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ORIGINAL ARTICLES.

The Contaminated Granite of Bibette Head, Alderney.

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Introduction and Previous Literature.

THE Bibette Head granite outcrops along the western portion of the north coast of Alderney. The outcrop, as seen at present, is about five-eighths of a mile long in an E.-W. direction and about one quarter of a mile wide. The greater part of the intrusion must, however, be under the sea. The rocks into which this granite is intruded are a rather variable series of diorites, and the contact is a sharp one, although there is a certain amount of veining by the granite. Over a large part of the outcrop the granite is much decomposed and reddened. This would appear to be due largely to the action of iron-bearing solutions, derived from the magma, coming up along fissures which are parallel to the main joint planes. These run in a direction 17° west of north. The same series of solutions were probably responsible also for the epidotization of the granite which is a marked feature in various parts. Recent blasting operations at Bibette Head have exposed a large quantity of fresh granite, and although specimens were collected from all over the outcrop the bulk of the material with which the present investigation is concerned came from there.

The earliest description of the granite is that of the Rev. E. Hill (1),[1] and it has again been briefly mentioned by Bonney and Hill (2) and by Plymen (3). The most striking feature of the mass is undoubtedly the large number of inclusions of a dark basic rock which it contains, as noted by Plymen. The presence of such a number suggests that the granite may have been modified by them.

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[1] Numbers in parentheses refer to list of references given at the end of the paper.

Detailed petrological examination of the intrusion shows that this is indeed the case, and that the granite has gained material in two or three different and equally interesting ways.

Petrology of the Granite.

(*a*) *Macroscopic.*—Where not reddened and decomposed, the granite is a medium-grained rock in which a rather abundant but varying quantity of black mica and hornblende, both often showing fairly good idiomorphic outlines, are easily visible to the naked eye. The other constituents which can be seen are a large amount of plagioclase felspar having a white or pale greenish colour, poikilitic plates of a flesh-pink alkali felspar which have a rather sporadic development, and a varying amount of colourless quartz. The proportions of these minerals vary a good deal even in different parts of the same hand-specimen. It is difficult to find a specimen of any size which does not show one or more of the dark basic inclusions. Even with an apparently homogeneous specimen closer examination usually shows the presence of small darker areas which represent remnants of original inclusions.

(*b*) *Microscopic* (Figs. 1, 2, and 3).—In thin section the granite is seen to be composed essentially of plagioclase, quartz, microperthite, hornblende, and biotite with sphene, magnetite, apatite, zircon, chlorite, sericite, zoisite, and epidote as accessories. The proportions of the essential constituents vary greatly from place to place and even in sections taken close together from the same hand-specimen. Some idea of the variation encountered may be gained from the following table. I and II were taken from the same hand-specimen within two and a half inches of each other, and III and IV from another hand-specimen within two inches of each other.

	I.	II.	III.	IV.
Plagioclase . .	50·4	53·2	54·5	36·1
Quartz . . .	14·6	19·0	18·3	17·1
Microperthite . .	28·6	15·7	14·8	26·4
Biotite . . .	5·6	7·3	10·8	9·0
Hornblende . .	0·8	4·8	1·6	11·4

The table brings out the fact that, although the proportions of all the minerals vary, yet the greatest variation is to be found in microperthite, hornblende and biotite. Quartz especially appears to play a more or less passive rôle with little variation in all four sections. It will be noticed, moreover, that there is nothing systematic about the variation of the minerals. There are no sympathetic or antipathetic relationships. We may now pass on to consider the character of the individual minerals in more detail.

Plagioclase.—The plagioclase felspar is nearly always the most abundant constituent. It is usually hypidiomorphic, but may sometimes show good idiomorphic outlines. It is generally well twinned on the albite, Karlsbad and, less frequently, the pericline laws. Two very distinct grain sizes can be noted, (*a*) normal granite size, crystals of which may run up to 6 mm. × 4 mm., and (*b*) crystals of much smaller size with lath-shaped, squarish, or rounded outlines. These last may be enclosed in quartz, microperthite or in (*a*). Many of the plagioclase crystals enclose minute needles of apatite, whilst others have globular inclusions of biotite or small idiomorphic crystals of hornblende. There may also be inclusions, usually only seen under a high power, of microperthite. Some of the plagioclase, on the other hand, does not contain any of these inclusions. It has been sericitized to a varying extent. The sericite is usually accompanied by zoisite in tiny granules and sometimes by a little epidote. Zoning of the crystals is, on the whole, not a very marked feature, but is by no means absent. When it does occur the core has a composition about $Ab_{85}An_{15}$ and the margin $Ab_{93}An_{7}$. The bulk of the plagioclase, however, centres round $Ab_{90}An_{10}$ with little variation on either side. When this plagioclase is enclosed either partially or wholly by quartz it remains quite unaffected, where it has been enclosed by microperthite some interesting changes take place at the margins. In the first case the microperthite exercises a strong corrosive influence on the plagioclase and the

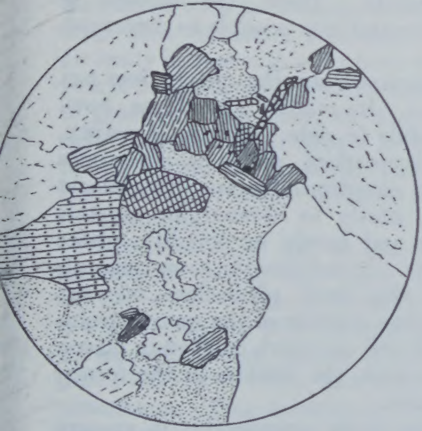

FIG. 1.

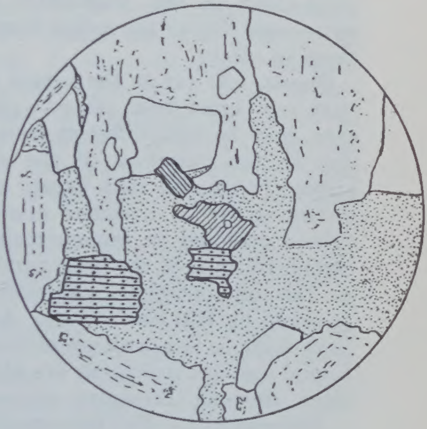

FIG. 2.

FIG. 1.—The granite, showing a clot of hornblende crystals with some sphene and a large flake of biotite. The remainder of the section is composed of plagioclase, microperthite (dotted) and quartz (blank). Notice the small corroded lath-shaped crystals of plagioclase lying in the microperthite near the hornblende clot. Both the clot and the small felspars represent xenolith material mechanically incorporated by the granite. Ordinary light × 24.

FIG. 2.—Section of the granite showing plagioclase, quartz, and microperthite, biotite, and a little hornblende. Notice the idiomorphic outline of the quartz towards the south-east where enclosed by microperthite. Ordinary light × 24.

margins of the crystals are eaten away. Often, though, the plagioclase has armoured itself against attack, and it does this in two distinct ways. In one, it develops an extremely narrow border of untwinned felspar which appears to be albite. In the other and commoner way, it develops a narrow border of myrmekite. This has its convex surface towards the microperthite but this does not necessarily mean that it is replacing the potash felspar. In rare instances the plagioclase develops both borders together. Exactly similar features may be noticed where microperthite encloses plagioclase in the Dalbeattie granite. There, the borders of untwinned felspar are rather broader and it is possible to determine them as albite.

Quartz.—As far as the actual amount goes, the quartz does not vary very much from place to place. Its relative abundance, however, may be very different from slide to slide. This is, in reality, due to the variation of the microperthite which is sometimes greater in amount than quartz and sometimes less so. The quartz occurs partly in irregular grains, partly in idiomorphic crystals (where enclosed in microperthite) and partly in poikilitic plates similar to those of the microperthite. It includes the same minerals as the microperthite, especially the small plagioclase felspars, as noted by Hill (see above). A large number of the quartz grains show more or less evidence of strain and are much cracked in places. Liquid and gas inclusions are abundant, the bubbles of the former often showing Brownian movement.

Microperthite.—The microperthite varies considerably in amount from place to place. It may be almost twice as abundant in one section as it is in another. It was probably the last mineral to cease crystallizing, as quartz may show good idiomorphic outlines against it and it is poikilitic or interstitial in habit. It encloses the larger plagioclase crystals, quartz, the larger biotite and hornblende crystals partially, and occurs also as large plates enclosing the smaller generation of plagioclase, biotite and hornblende completely. Needles of apatite are generally associated with these when they are enclosed. The two main cleavages are very well developed and the albite of the intergrowth, viewed under a high power, appears to be present in three distinct ways:—

(*a*) The albite forms very thin lamellae which may resemble fine albite twinning in plagioclase. These lamellae make an angle of about 70° with the (001) cleavage as seen in sections parallel to (010) (4).

(*b*) The albite is still roughly parallel to the same direction but occurs in broader and lenticular shaped masses.

(*c*) The albite may have what appears to be a quite irregular distribution.

Extinction angles on (010) faces indicated a soda content of about 20 per cent (5). It is doubtful if this result can be considered as strictly accurate.

Biotite.—The biotite is present as ragged flakes which are pleochroic from a medium straw to a muddy chocolate brown. It occurs as normal sized flakes and also as much smaller ones which may be enclosed by quartz, microperthite or plagioclase. Where enclosed by plagioclase, more particularly, it is found that this latter mineral always carries minute needles of apatite. Occasional basal sections of the biotite may show fairly good outlines. Inclusions of apatite in the biotite and in its immediate vicinity are very common. Some of the biotite is so intimately associated with hornblende as to leave little doubt of its derivation from that mineral. Normally, the biotite has $\beta = 1{\cdot}647 \pm {\cdot}002$. In many instances it is far from fresh. In the early stages of alteration it becomes paler in colour and excretes granules or small crystals of sphene. Sometimes, at this stage, the margins turn green but still retain the birefringence proper to biotite. At a later stage the margins alter to penninite, which alteration also extends along the cleavage planes. Finally, the whole flake is pseudomorphed by penninite.

Hornblende.—As will be seen from the table already given, the hornblende varies very much in quantity in different sections. On the whole it has a tendency to be distinctly idiomorphic. It is a green variety with X, very pale greenish; Y, brownish green; Z, medium green, and $Z \wedge c = 22°$. It is biaxial negative with $\alpha = 1{\cdot}657$, $\gamma = 1{\cdot}676$ and $\Delta = {\cdot}019$. Twinning on 100 is not uncommon. This hornblende, again, is found in two generations. The smaller generation is often highly idiomorphic and may be enclosed in plagioclase, microperthite or quartz. This smaller generation is of less frequent occurrence than that of normal size, as is also the case with the smaller generations of plagioclase and biotite. A certain amount of magnetite and apatite are usually found in association with it.

Sphene.—A pale brown sphene, pleochroic from very pale to darker brown, is present in most instances but is not particularly abundant. It may occur in wedge-shaped crystals or may be allotriomorphic, in which case it sometimes partly encloses small plagioclase crystals. It is nearly always closely associated with the hornblende. There is also a certain amount of secondary sphene occurring with chlorite where this latter mineral has replaced biotite.

Magnetite.—Apart from the magnetite enclosed in hornblende and biotite or occurring in their immediate vicinity, there is little if any in the rest of the rock.

Apatite.—The distribution of apatite has been described already in connection with the essential minerals. In addition to its occurrence in some of the plagioclase and in the hornblende and biotite, it may be found in the quartz and microperthite. It is not at all abundant in these two minerals, however, except where they are in the immediate vicinity of hornblende and biotite. Small rod-like inclusions of an indeterminate nature may sometimes be seen in it.

Zircon.—One or two little crystals of zircon may usually be found enclosed by quartz or, more rarely, by felspar. It occurs occasionally in the biotite, but its presence there, as indicated by pleochroic haloes, is not common.

Sericite is found in minute flakes as a decomposition product of plagioclase. The microperthite is always exceedingly fresh.

Epidote.—Occurs sometimes in granules associated with the sericite derived from the alteration of plagioclase. More rarely it may accompany chlorite, which in this case has been probably derived from hornblende.

Zoisite.—Is usually associated with sericite. Generally it is minutely granular in habit, but occasionally it is found to occur in larger grains.

Chlorite is of fairly frequent occurrence, partially or wholly replacing biotite. The chlorite belongs to the penninite group.

A. W. Groves (6) has given a list of the heavy minerals which he found in the Bibette Head granite. The following are his results :—zircon, very common ; apatite, very common ; biotite, abundant ; hornblende, abundant ; sphene, abundant ; epidote, scarce ; clinozoisite, scarce ; zoisite, scarce ; chlorite, very common ; magnetite, less common ; haematite, scarce. Sphene and zircon appear to be rather more abundant than microscopical examination of thin sections would suggest. He gives the percentage weight of heavy minerals (the index figure) as 17·1. In discussing the importance of the index figure he says (7), " While the figures for granite are elastic, figures between about 10 and 20 indicate assimilation." According to this view, therefore, the high index figure of the Bibette Head rock is evidence of its contamination.

Texture and Microstructure.—The texture of the rock is monzonitic. There is, moreover, a very definite tendency for the larger plagioclases to occur in aggregates of two or three individuals. There is a no less definite tendency for the biotite and hornblende to occur in clots accompanied by magnetite, minute needles of apatite and, sometimes, by sphene. In some instances these clots contain small laths of plagioclase which also carry apatite needles. In other cases these small laths occur enclosed in microperthite and quartz in the immediate vicinity of the hornblende-biotite clots and in yet other examples, the larger plagioclases nearby may contain inclusions of apatite together with small crystals of hornblende and biotite. These features, which at first glance would go unrecognized, have an important bearing on the origin of much of the hornblende, biotite, and plagioclase. It is believed that a portion of these minerals has been derived from the incorporation of basic igneous material which was originally of doleritic nature. The evidence on which this statement rests and the ways in which the magma incorporated the material will be examined in the following pages.

Epidotization of the Granite and the Xenoliths.—Very often it is found that the granite and its accompanying xenoliths have been epidotized to a certain extent. This is particularly the case near the contact with the surrounding rocks, but it is also found in the main body of the mass. In general, the xenoliths appear to have been more affected than the granite. During this epidotization, the quartz and microperthite remain unchanged, although the latter may show slight sericitization. The plagioclase felspar has been greatly sericitized, the sericite flakes being accompanied by granular epidote or zoisite. Some of the hornblende remains fresh, but some is changed to a green penninite with epidote and, sometimes, secondary sphene. The biotite has been more liable to alteration and has nearly all gone over to penninite and secondary sphene. The epidote may be highly coloured or almost colourless. It occurs associated with the chlorite, with sericite in the plagioclase and as small independent masses or single grains, usually enclosed in felspar but also occurring interstitially. Again, it is sometimes found veining quartz. Haematite also accompanies it. It is difficult to know how far the epidote has been introduced or how far it has been derived from the molecular rearrangement of the minerals already present. In any case there can be no doubt that solutions rich in water have been primarily responsible for the changes which have taken place. These solutions were presumably released just after the final consolidation of the granite.

There is also another type of epidotization seen in the granite, namely, that connected with crushing. Here all the constituents of the granite have been crushed down into finer fragments though, in places, traces of the original texture remain. The plagioclase has changed to pure albite and shows a great development of secondary twinning with bending, slipping, and faulting of the lamellae. On the whole, however, plagioclase has withstood crushing better than the other constituents. The microperthite has developed a dusty appearance, and its albite has separated into more definite stringers. It has not resisted the crushing as well as the plagioclase. Quartz has suffered most, but the fragments show little sign of strain which rather suggests that solutions may have been active as well and that the crushing was accompanied by a certain amount of recrystallization. Biotite and hornblende have disappeared, but epidote occurs abundantly and is particularly rich in certain bands. It is only faintly coloured. A little zoisite may also be present. The large amount of epidote suggests that some of it must have been introduced. There is also a fair amount of pale green, almost isotropic chlorite. Some of it, occurring more particularly in the quartz, is vermicular in habit.

The Xenoliths and the Contamination Process.—(*a*) Xenoliths of Sedimentary Origin: Although by far the greater bulk of the xenoliths found were of igneous origin, yet there were one or two to which an original sedimentary nature must be attributed. These have an interest of their own in as much as the only sediments known on the Island are the Cambrian series of grits, etc., which are supposed to lie unconformably on the dioritic series into which the Bibette Head granite is intruded. Three sedimentary xenoliths were found, all of which differ from the normal xenoliths of the granite by having angular instead of more or less rounded outlines. All three possess a typical hornfels texture under the microscope.

The first inclusion is composed of a granular aggregate of hornblende, quartz, and felspar. The hornblende is the most abundant constituent, occurring either as grains or in small, very irregular plates partially or wholly enclosing the quartz and felspar. It also contains inclusions of magnetite in places. In colour and pleochroism it resembles the hornblende of the granite. Quartz is the next most abundant constituent and contains many minute dusty inclusions, also liquid and gas inclusions. Further there are small colourless inclusions of lower refractive index. These are believed to be inclusions of felspar. The felspar of the xenolith is apparently an albite-oligoclase, although a good deal of it is untwinned. It is slightly sericitized and may enclose globular biotite and magnetite. Biotite, in small brown flakes, is rare. Apatite is common, generally enclosed in quartz and felspar, and there are a few rounded grains of zircon. At its immediate contact with the granite, the xenolith is represented by a narrow zone in which the grains of hornblende have developed into large crystals enclosing many of the felspar grains. This zone would also seem to be richer in felspar than the main body of the inclusion. It has been penetrated to a certain extent by the microperthite and quartz of the granite. Apart from this, there is no sign of assimilation by the granite.

The next two inclusions are both of the same type, but one is in a more advanced stage of alteration than the other. In the least altered example the rock is essentially composed of biotite and felspar. The felspar is the most prominent constituent, being again an albite-oligoclase. It encloses small grains of magnetite and, less commonly, globules of biotite. The biotite is fairly abundant in flakes of varying size which are pleochroic from pale straw to dark red-brown. Apatite needles, often very minute, are abundant. Rounded grains of zircon occur fairly commonly. In the more altered example, some parts are quite similar to what has just been described, but in many parts the inclusion has been completely sericitized. These patches give the rock a spotted appearance in hand specimen. In these sericitized areas the felspar has been altered to an aggregate of small sericite flakes. Scattered through the general sericitic groundmass there are irregular areas of coarser crystallization. These are composed of white mica, pale green chlorite, a little altered biotite, zoisite and clinozoisite, together with some magnetite. This example shows an increased activity of the volatile components of the magma in modifying the composition of the inclusion. A rather similar type of alteration has been recently described by Osborne (8). In both these inclusions the microperthite of the granite has wedged the little felspar grains apart at the contact. Apart from this there has been little disintegration.

All three inclusions would appear to have been derived from impure grits. The first from a calcareous, chloritic grit carrying a certain amount of albite ; the other two from a similar rock but of much less calcareous nature. It is possible, perhaps even probable, that some of the albite molecule has been introduced by the magma during recrystallization.

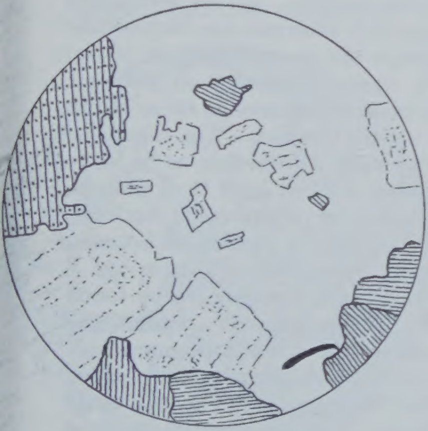

Fig. 3.

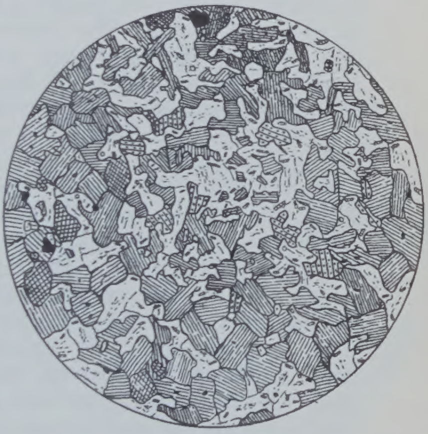

Fig. 4.

Fig. 3.—Section of the granite showing small crystals of plagioclase and hornblende enclosed in a plate of quartz. The other constituents are plagioclase, hornblende, and biotite (to the north-west). Ordinary light × 24.

Fig. 4.—The least altered type of basic igneous xenolith, showing lath-shaped plagioclase, hornblende, some biotite, magnetite, and needles of apatite. Ordinary light × 24.

(*b*) *Xenoliths of Igneous Origin and the Mechanism of Contamination.*—Inclusions of a dark, fine grained, basic rock are evenly distributed throughout the whole outcrop of the granite and are extremely abundant. They correspond to the " basic segregations " of older writers and range in size from some a foot or more long to others of microscopical dimensions. All agree in having more or less rounded outlines. The larger xenoliths are of comparatively rare occurrence and those a few inches in size or less are by far the commonest. Their even distribution suggests that they have not been derived from the rocks in contact with the granite at the present time, but that they have either been brought up from below or have sunk down from the original roof. They are found in all stages of dissolution and disintegration and in Fig. 8 a series of drawings from polished surfaces shows the gradual disappearance of a xenolith.

In their least altered condition the xenoliths are dark, fine-grained rocks. In thin section they are composed essentially of roughly equal proportions of plagioclase felspar and ferromagnesian minerals (Fig. 4). The plagioclase occurs largely as small laths, thus retaining an original doleritic texture. The laths are twinned on the albite and Karlsbad laws. A fair proportion show only a shadowy type of twinning or else none at all. The plagioclase is usually zoned, corresponding to a composition of about $Ab_{70}An_{30}$ in the centre to about $Ab_{87}An_{13}$ or $Ab_{90}An_{10}$ at the margin. All are sericitized to a certain extent. The ferromagnesian minerals are hornblende and biotite. The hornblende is always the more abundant of the two, but the proportion of biotite varies somewhat in different examples. Both minerals have the same characters as those found in the granite, but the biotite is usually fresher. The biotite is normally so intimately associated with the hornblende as to leave little doubt that the bulk of it has been derived from that mineral. Both are present with hypidiomorphic or idiomorphic outlines, and also as small irregular plates filling up the interstices between the laths of plagioclase. Magnetite is associated with them but is not abundant. One or two small grains are, however, to be found in most of the hornblende crystals. Some sphene is present and apparently becomes more abundant as the biotite becomes less. This would indicate that the biotite is a titaniferous variety and that only the titanium left over after the formation of biotite could combine with the lime to form sphene. There is an abundance of small needles of apatite, the bulk of which are enclosed in the felspars and serve to indicate the important part played by volatiles in the recrystallization of the xenoliths. The apatite needles are scattered all through the felspars in the xenoliths and not found only in the margins of the crystals. This shows that the whole of the felspar has been altered and not merely the margin as in some other examples (9). These xenoliths would appear to have been originally of doleritic nature. As there is no trace of original augite and the hornblende has the crystal outlines proper to it, it might be suggested that the xenoliths were dioritic rather than doleritic in their pristine condition. Against this there is the evidence of the lath-shaped felspars and their fine-grained texture. Moreover, the diorites surrounding the intrusion are of very miscellaneous character, ranging from acid quartz-bearing varieties to basic ones carrying some augite. These are presumably typical of the series which occupied the space now taken by the granite and it seems almost impossible for such a variable series to have given rise to a large quantity of uniform evenly distributed xenoliths. Finally, they are identical in texture and mineral composition with other xenoliths enclosed in various granites and where an original doleritic nature can be demonstrated. Thus the xenoliths here bear no relation to the surrounding rocks, in which respect they fall into line with those of Strath, Skye, and Dhoon, Isle of Man. Although, throughout the greater part of the xenolith the texture is that of a medium grained dolerite yet, in certain areas, the biotite and hornblende may form larger crystals. These may occur separately or be segregated into clots.

At a slightly later stage in their alteration the xenoliths start to grow " phenocrysts " or porphyroblastic crystals (Fig. 5). These are of plagioclase which has the same composition as that of the granite. It might well be argued that these " phenocrysts " are original and that the dolerite which gave rise to the xenoliths was porphyritic in some parts and non-porphyritic in others. Against this view, however, there is a good deal of evidence. In the first place the number of " phenocrysts " becomes greater as the xenoliths become more altered. The most important point is the fact that these " phenocrysts " contain minute inclusions of a felspar of a lower refractive index and with shadowy extinction. In some cases good cleavage can be seen, a feature characteristic of the microperthite found in the granite. Further, these inclusions have not been found in the plagioclase laths which form the body of the xenolith. There is little doubt that the felspar inclusions are of microperthite, thus proving that the magma must have contributed

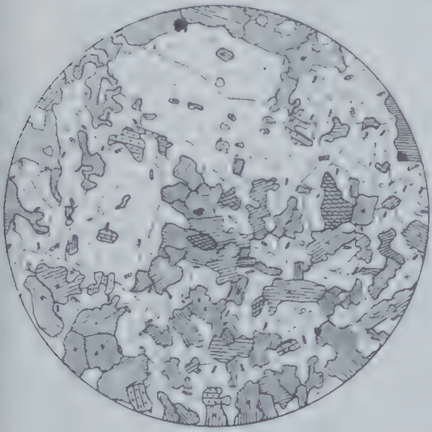

Fig. 5.

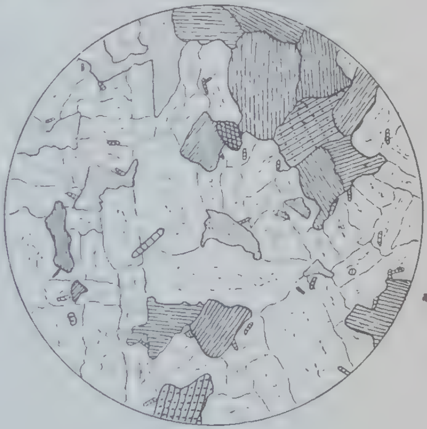

Fig. 6.

Fig. 5. A more altered xenolith showing the development of three phenocrysts of plagioclase. Ordinary light × 24.

Fig. 6.—A later stage in the alteration of the xenoliths. This shows the large increase in grain size and the beginnings of the entry of microperthite (dotted in the drawing). Ordinary light × 24.

in some measure to the formation of the "phenocrysts". Moreover, the hornblende and biotite in the vicinity of the "phenocrysts" have generally a larger grain size than usual. This shows that conditions favouring their growth were active at these points. Thus there seems to be a fair amount of evidence to indicate that these "phenocrysts" have grown during the time when the xenoliths were immersed in the magma and that they are not original constituents. They appear to have grown partly by replacing small plagioclase laths, the evidence for this being the occurrence of normal sized hornblende and biotite crystals in them, and partly by pushing material aside. The hornblende and biotite occurring along the edges of the "phenocrysts" are often partially enclosed at the margin. In addition to the inclusions of felspar, hornblende, and biotite, noted above, they also contain much smaller grains of hornblende and biotite together with minute needles of apatite. Such phenocrysts of euhedral felspar formed by the action of acid magma on basic xenoliths have also been noticed by Clapp (10). With the arrival of these "phenocrysts" there is a strong tendency for the biotite and hornblende to segregate into distinct patches or clots. These have usually a rather larger grain size than the average, which, in its turn, is slightly greater than that of the least altered xenoliths. At the margin of the xenoliths, the grain size becomes much greater and a certain amount of material can be seen in process of incorporation into the granite.

As alteration proceeds, the "phenocrysts" gradually become more abundant. They are then found to be commonly in aggregates of two or three individuals associated with hornblende and biotite, the crystals of which reach normal granite size. The clots of "phenocrysts" are sometimes associated with a little interstitial quartz and microperthite showing, once again, the part which the magma has played in their formation. As the "phenocrysts" become more abundant, the average grain size of the groundmass also becomes greater, thus lessening the contrasts between the "phenocrysts" and the groundmass. The large crystals of hornblende and biotite also become more abundant. At this stage quartz and microperthite begin to occur interstitially throughout the xenolith (Fig. 6). The xenolith could now be termed a quartz-diorite and, under the microscope, the boundary between it and the granite is quite vague and undefined. Finally, a stage is reached when the grain size of all the constituents is nearly the same and the xenolith is only defined from the granite by the fact that it is rather richer in plagioclase, hornblende, and biotite. An increase of quartz and microperthite in the xenoliths would render them indistinguishable. Thus all stages can be found from a fine grained xenolith of original doleritic nature to one which, by growth of "phenocrysts" of plagioclase and concomitant increase in size of the other constituents together with the introduction of microperthite and quartz, has become almost indistinguishable from the granite.

some more microperthite and quartz, and the xenolith would be the granite and all trace of the former would be lost. With regard to the introduction of quartz and microperthite, it may be noted that these minerals do not replace any constituents of the xenolith but wedge their way in between them. There is no doubt that this is a very effective method of incorporating material and one which would leave little or no trace of its accomplishment. Not only does the magma incorporate hornblende and biotite but also plagioclase. The plagioclases of the xenoliths all carry minute needles of apatite or inclusions of hornblende and biotite whilst the "phenocrysts" carry microperthite in addition. In the "normal" granite itself some of the plagioclase, as already mentioned, carries these same inclusions with exactly the same characters. There seems little doubt that some of the plagioclase carrying these inclusions has been derived in the same manner as outlined above. There is little doubt also that the clots of biotite and hornblende occurring in the granite have been derived, in part, in the same manner, as exactly similar segregations are found in the xenoliths themselves.

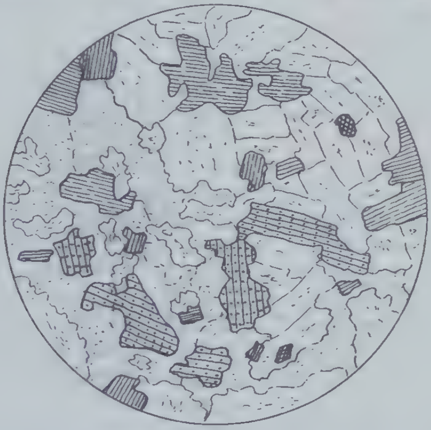

FIG. 7.

FIG. 7.—Junction of xenolith and granite. The xenolith can be seen in the north-east portion of the drawing. Further down, the microperthite (dotted) of the granite is actively corroding the plagioclase of the xenolith and is incorporating the plagioclase, biotite, and hornblende of the xenolith into the granite. It will be noticed that the microperthite wedges the minerals of the xenolith apart and incorporates them into the granite as complete crystals. Ordinary light × 24.

In addition to the changing and incorporating of the xenoliths dealt with above, the granite has also attacked the margins of the xenoliths and the rest of the incorporated material has been derived from this (Fig. 7). This marginal attack takes place at every stage from the original fine grained xenolith to the one which, to all intents and purposes, has almost become a part of the granite. In the latter case, of course, the marginal attack is indistinguishable from the general disintegration of the xenolith. In the less altered xenoliths the margins are of coarser grain than the interior, though a fair amount of the small laths of plagioclase, the small hornblende, and biotite crystals still remains. The granite incorporates this marginal material by wedging the constituent minerals apart. This is accomplished by the microperthite and quartz. These minerals are wedged in and form poikilitic plates which partially enclose the larger plagioclase, hornblende and biotite crystals, and completely enclose the small laths of plagioclase and the smaller crystals of hornblende and biotite. Of the two minerals, the microperthite would appear to be the more active, and, in addition, it exercises a very strong corrosive action on the small laths of plagioclase and all stages of their dissolution can be seen. Some of them, however, armour themselves against further attack in the manner already dealt with when describing the petrology of the granite. The larger plagioclases are also attacked, though not to the same extent, due no doubt to the fact that a substance in a fine state of division is more readily soluble than the same substance in larger particles. It may be suggested that this attack by the microperthite is due to the fact that the plagioclase is not in equilibrium owing to its derivation from the xenoliths. In the case of plagioclase crystallizing from the granite, this is also out of equilibrium owing to its taking up lime from the xenoliths during reciprocal reaction.

Quartz, on the other hand, exercises no such corrosive influence. This would account for the fact that the small lath shaped plagioclases are more abundant in the quartz of the " normal " granite than in the microperthite. For, in view of the evidence of incorporation of material given above, there can be little doubt that the small laths of plagioclase found included in microperthite and quartz have been derived from xenoliths.

Thus, certain slightly peculiar features of the granite such as the inclusions of lath-shaped plagioclase; the small hornblende and biotite crystals found in the quartz and microperthite; the small hornblende and biotite crystals and the minute needles of apatite found in some of the larger plagioclase crystals; and the close association of a great deal of the biotite and hornblende with their tendency to occur in clots, sometimes associated with small plagioclase crystals, are all satisfactorily explained by the incorporation of the xenolithic material by the granite. This also accounts for the high index figure. There is no means of determining the exact amount of contamination which the granite has suffered because the original granite is nowhere to be seen. The whole mass, as at present visible, is uniformly contaminated. Judging from the amount of material which can be seen in actual process of incorporation at the margins of the xenoliths and reflecting that a greater amount has probably been incorporated in the other way

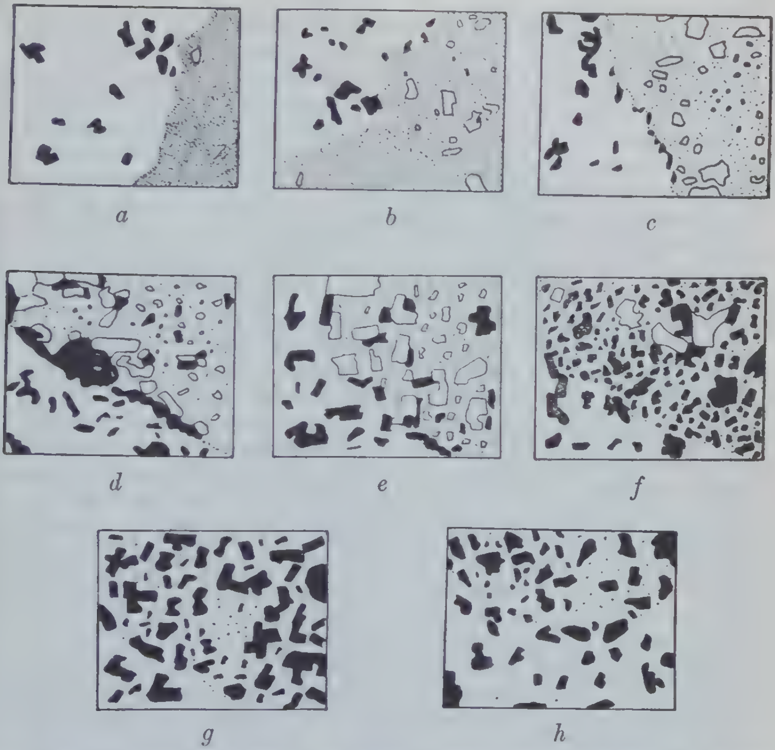

FIG. 8.—The figure illustrates the gradual incorporation of a xenolith as seen on polished surfaces of the rock specimens.

a. Shows the initial stage. The dotted part is the fine-grained xenolith, whilst the white part is the granite. The black portions are the dark minerals, hornblende and biotite.

b. Shows a xenolith which has begun to develop phenocrysts of plagioclase. The lighter stippling indicates a slight increase of grain size in the general mass of the inclusion.

c. Is a further stage in the development of "phenocrysts".

d. Shows a slightly later stage when large crystals of the dark minerals of the xenolith have begun to accompany the "phenocrysts" of plagioclase. It also shows the dark minerals gathered at the margin where they are being incorporated by the granite.

e. Still more "phenocrysts" have developed, many of the white patches now representing two or three individuals and there has been an increase in the large crystals of the dark minerals. The general grain size of the whole xenolith has increased and its junction with the granite is not quite so well defined.

f. The grain size of the xenolith has again increased, so that only the aggregates of "phenocrysts" and not the individuals now stand out from the general groundmass. It is somewhere about this stage that quartz and microperthite begin to enter.

g. A further increase of grain size. The dark minerals are now very much the same size as those in the granite.

h. The final stage with further slight increase of grain size. The xenolith is now almost indistinguishable from the surrounding granite.

described, it would appear to have been considerable. The high index figure supports this view. It should be noted that the features which point to contamination in this particular example are very minor ones as far as the granite is concerned. If contamination had not been suspected, or if the granite had not been examined in detail, it would have passed as a perfectly normal rock.

It is of interest to notice that the described methods of incorporating material are mechanical. One depends on the growth of " phenocrysts " and the later introduction of quartz and microperthite with concomitant increase in grain size throughout the whole xenolith. The other depends on the introduction of quartz and microperthite at the margins alone. Any chemical reaction between the xenoliths and the magma had taken place before the disintegration of the xenoliths commenced. This shows that the xenoliths had been immersed in the magma for a considerable period of time before crystallization in the magma became advanced and suggests that the xenoliths were brought up from below by the magma. Although the introduction of microperthite and quartz alters the bulk chemical composition of the xenoliths, yet this alteration is produced by mechanical means and in no sense by reaction between xenolith and magma. In other words, equilibrium between the xenoliths and the magma had been established at an early period in their history and they remained more or less in equilibrium throughout. Further, besides incorporation of marginal material from the xenoliths which is a feature of most contaminated rocks, there is the far more subtle method by which the whole xenolith, in its final stage of modification, becomes almost indistinguishable from the granite. This mechanism involves the expansion of the xenolith as a whole. As the xenolith is lying in a plastic (or even fluid) medium, namely, the magma, this expansion involves no difficulties. The material introduced occupies space originally occupied by xenolithic material and this xenolithic material, forced out into the magma, occupies the space which would have been occupied by the introduced material if no introduction had taken place. Thus, although the xenolith itself expands, the volume of the intrusion, as a whole, remains the same.

With regard to reciprocal reaction, little can be said. This is because neither the original dolerite material which gave rise to the xenoliths, nor the uncontaminated granite are to be seen in the area. It seems fairly certain, however, that the original magma was of alkali-granite type. This is borne out by the small veins which are given off by the granite and which traverse the surrounding diorite. These are often rich in microperthite. For instance, one vein has the approximate composition: plagioclase 12·7%, quartz 20·8%, microperthite 57·3%, and chlorite (most of it apparently representing original biotite) 9·2%. Here, again, the quartz is present in about the same quantity as usual and the variation noted here when compared with the general mass of the granite is in the plagioclase and microperthite. There is little doubt that the xenoliths have lost lime to the magma and gained potash, soda, and alumina. Quite apart from the acidification of the basic plagioclase, the change from augite to hornblende still demands an influx of alkalies and alumina together with the removal of lime.

As neither the original granite nor the original basic rock are exposed to view, it is not possible to go any further than this and the nature of the reciprocal reaction cannot be worked out in as much detail as would be desirable. The interest of this present example lies in the fact that reciprocal reaction had apparently finished before mechanical disintegration commenced. Further, it shows that material may be added to the xenoliths after reciprocal reaction has ceased, as in the growth of "phenocrysts" and the introduction of microperthite and quartz. This is particularly significant because, if a xenolith with the "phenocrysts" and microperthite was analysed and compared with the original basic rock from which the xenoliths were derived it would not give a true picture of the bases gained and lost during reciprocal reaction. It is of the utmost importance, therefore, when studying the question of reciprocal reaction to be quite certain that there has been no addition of material to the xenolith from the magma other than that used during reciprocal interchange.

Comparison with other Areas.

In comparing the above contamination of an acid with a basic rock, it is natural to turn first to the classic examples in the Tertiary igneous province of the West of Scotland and Northern Ireland. The hybrids found in Skye (11), Mull (12), Arran (13), Ardnamurchan (14), and Carlingford (15), although bearing an obvious general resemblance to the Bibette Head occurrence, yet show significant differences. For instance, in most of these, augite (derived from original diallage of the xenoliths) is a stable phase in the contaminated rocks. This is to be connected with the nature of the invading rock, which was a granophyre rather than a true granite, and numerous occurrences go to show that augite is a prominent and stable ferromagnesian constituent of granophyres. True phase equilibrium appears to be rarely attained, no doubt owing to lack of time for complete reciprocal reaction to take place. This is abundantly proved by the presence of remnants of diallage and labradorite in the xenoliths and in the contaminated rocks. Thus, portions of the original basic material remain almost unaltered.

A further change towards phase equilibrium is shown by the altered gabbro (gabbro-diorite) near Tsukubamachi (16). Here, the original augite has almost completely disappeared, its place being taken by hornblende and biotite, and the plagioclase, though still showing labradorite cores in some places, is for the most part a good deal more acid, though less acid than that of the biotite-granite responsible for the alteration. The case described by Parkinson (17) from Sorel Point, Jersey, is very similar in many respects to that of Bibette Head. In the altered rock hornblende and biotite almost completely replace original augite and there is also impregnation of the " diabase " with orthoclase and quartz and corrosion of the plagioclase by the former.

The more altered xenoliths found in the granite of Mont Haya bear a very striking resemblance to those of Bibette Head. De Lapparent (18) describes originally gabbroic xenoliths in all stages of alteration and impregnation with granitic material. He finds the alteration to proceed in two different directions, the one characterized by biotite alone, the other characterized by hornblende, biotite, and sphene. It is this latter group that resemble the Bibette Head xenoliths.

Pabst (19) has recently published a paper on the inclusions in the Sierra Nevada granites. Most of these he terms " autoliths " in distinction to true xenoliths, because they are composed of the same minerals as the enclosing granite and bear no relationship to the contact rocks or the xenoliths derived from these rocks. They are quite obviously of igneous origin and in their content of plagioclase laths (zoned from An_{60} at the core to An_{20} at the margin), green hornblende, biotite, and, in many, their development of plagioclase " phenocrysts " and the gradual incoming of poikilitic potash felspar and quartz, they bear a most marked resemblance to the xenoliths at Bibette Head. Like them, also, the " phenocrysts " may enclose small idiomorphic hornblendes and apatite " may show a notable concentration ", being included in the plagioclase as fine acicular prisms. Pabst comes to no definite conclusion as to their origin but in view of the evidence from Bibette Head and other occurrences there seems little doubt that his " autoliths " represent xenoliths of basic igneous rock brought up from below.

More recently Wells and Wooldridge (20) have dealt with the intrusion of a red alkali-granite into a gabbro sheet at Ronez, Jersey. In the xenoliths of gabbro found there augite has been completely replaced by hornblende and biotite. Apatite is abundant and some of these xenoliths are described as being of tonalitic nature, so presumably their plagioclase has been considerably acidified. Apart from the development of " phenocrysts ", they appear to be very similar to some of those found at Bibette Head. It is interesting to find that the red granite, in its richness in microperthite, its quartz content of about 25 per cent, and its albitic plagioclase must resemble very closely the type of magma which must have caused the alteration of the xenoliths at Bibette Head.

At Bibette Head itself, almost complete phase equilibrium appears to have been reached as a result of reciprocal reaction. Here, no trace of original augite remains and the plagioclase of the more altered xenoliths has largely been made over to the same composition as that present in the granite. It is interesting to note that, in general, equilibrium for the ferromagnesian minerals seems to be attained more readily than for plagioclase (see also (21)). That this equilibrium has been attained between xenoliths and magma does not necessarily imply that it will be retained throughout the whole cooling history of the latter. At Bibette Head, equilibrium does seem to have been fairly well established for the whole period, but the active corrosion of plagioclase by microperthite shows that even here quite complete equilibrium was not maintained in the later stages. Such close equilibrium between the xenoliths and the magma indicates that the cooling of the latter must have been comparatively slow and that the xenoliths were immersed in the magma for a long time. This is in agreement with the fact that the original material of the xenoliths is not represented amongst the surrounding country rocks as at present exposed, and suggests (as noted before) that they came from below rather than from above.

The number of examples where xenoliths (also including under this term many of the "basic segregations" of older writers) of basic igneous rock, enclosed in granite, bear no relation to the surrounding rocks is gradually increasing, and it can be predicted with a fair amount of confidence that many more examples will be found in the future. All the evidence in these cases points to the xenoliths as coming up from below with the magma. The basic rock from which the xenoliths are derived probably formed a small boss through which the granitic magma broke during its upward passage. This boss, though occupying much the same position as the granite mass, need not have had the same areal extent. The work of Cloos and his students has shown that many large granite masses have reached their present positions through quite small openings and have spread above these to the dimensions which we now see. The close association of basic and acid rocks seen in so many laccoliths, sills, and composite dykes suggests that in many cases of plutonic intrusion as well, a basic rock may well precede an acid one, being later broken up to form attenuated fragments in the larger visible volume of the acid intrusive.[1]

LIST OF REFERENCES.

(1) E. Hill. *Quart. Journ. Geol. Soc.*, xlv, 1889, 382.
(2) T. G. Bonney and E. Hill. *Quart. Journ. Geol. Soc.*, lxviii, 1912, 34.
(3) G. H. Plymen. *Trans. La Societe Guernsiaise*, 1922, 7 and 13.
(4) C. E. Tilley. *Quart. Journ. Geol. Soc.*, lxxvii, 1921, 86.
(5) H. L. Alling. *Journ. Geol.*, **xxix**, **1921**, **231**.

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[1] Since this paper was completed, a study of the xenoliths of igneous origin in the Trégastel-Ploumanac'h Granite has been published by Dr. H. H. Thomas and W. Campbell Smith (*Quart. Journ. Geol. Soc.*, lxxxviii, 2, 1932, 274–95). Many of their xenoliths seem to agree rather closely in mineral constitution with those of Bibette Head, but the quartz ocelli and the rapakivi felspars described by them have not been found in the latter locality. They also agree with the writer in regarding the cognate xenoliths and basic segregations of many granites as being due to the incorporation of hybridized basic rocks.

(6) A. W. Groves. Geol. Mag., LXIV, 1927, table facing p. 464.
(7) —— Loc. cit., 472.
(8) G. D. Osborne. Geol. Mag., LXVIII, 1931, 313.
(9) J. de Lapparent. *Bull. Soc. Min. France*, xxxvi, 1913, 145.
(10) C. H. Clapp. *Bull. U.S. Geol. Surv.*, 704, 1921, 115.
(11) A. Harker. "Tertiary Igneous Rocks of Skye": *Mem. Geol. Surv. U.K.*, 1904, chap. xi.
(12) "Mull Memoir": *Mem. Geol. Surv. Scot.*, 1924, chap. xxxiii.
(13) "Geology of Arran": *Mem. Geol. Surv. Scot.*, 1928, 145–7, 175–8.
(14) "Geology of Ardnamurchan": *Mem. Geol. Surv. Scot.*, 1930, 100–2, 260–2, 337–40.
(15) W. J. Sollas. *Trans. Roy. Irish Acad.*, xxx, 1894, 477–512.
(16) K. Sugi. *Jap. Journ. Geol. and Geog.*, viii, 1930–1, 43–52.
(17) J. Parkinson. *Quart. Journ. Geol. Soc.*, lv, 1899, 430–47.
(18) J. de Lapparent. Loc. cit., 143–72.
(19) A. Pabst. *Univ. California Geol. Bull.*, xvii, 1928, 325–68.
(20) A. K. Wells and S. W. Wooldridge. *Proc. Geol. Assoc.*, xlii, 1931, 182–206.
(21) K. Sugi. Loc. cit., 52.

The Geology of Moncreiffe Hill, Perthshire.

By Charles F. Davidson, University College, Dundee.

A. Introduction.
B. Field Relations.
  (i) The Lavas.
  (ii) The Intrusions.
  (iii) The Sediments.
C. Petrography.
  (i) The Lavas.
D. Petrogenetic Considerations.
E. Conclusion.

Introduction.

Moncreiffe Hill, Perthshire, is the inclusive name for the series of low hills which form the uplands to the south and south-east of the City of Perth, and whose heather and grass-covered slopes reach in the summit of Moncreiffe Hill proper, a height of 725 feet above sea-level. The alluvium of the River Tay forms the northern boundary of the area under consideration, while on the east and south-east the hills are bounded by a continuation of the northern of the two faults which let down the Upper Old Red Sandstone outlier of the Carse of Gowrie, and by the Carse and Arctic clays of the River Earn. To the east of the City of Perth the area is bounded by the Lower Old Red Sandstone.

Geologically, the series of hills is composed of lava-flows of Lower Old Red Sandstone age, and the area forms the most westerly exposure of the long range of the Sidlaw Hills, from which it is cut off by the River Tay. It thus lies on the northern half of the

Sidlaw-Ochil anticline, and the long slopes of the successive lava-flows consequently dip towards the north-east, the southern slopes of the hills showing a fine series of mural scarps.

The volcanic rocks rest on, and are intercalated with, sandstones, conglomerates, and ashes of many textures and types, red, green, or yellow in colour. These are of Lower Old Red Sandstone age, but rocks of Upper Old Red Sandstone age, faulted against the lavas on the southern boundary of Moncreiffe Hill, have been mapped by the Geological Survey. No outcrop of this sandstone is at present available for study, but it is obviously high up in the stratigraphical sequence as it grades into the Lower Carboniferous of Dron on the opposite side of the River Earn.

The series of lava-flows and sediments is pierced by several east–west quartz-dolerite dykes, presumably of Permo-Carboniferous age.

No detailed description of the area has previously been issued, but many isolated references to structural features may be found, from the time of Ami Boué (1) [1] to the present day. Mapping on a 6-inch scale for the Scottish Geological Survey was carried out by James Geikie, and the results are incorporated in 1-inch sheet 48, published in 1883. Several accounts of the large-scale features of the lavas, sediments, and dykes are made by the same author in some early *Transactions of the Perthshire Society of Natural Sciences* and by Macnair in *The Geology, Geography, and Scenery of the Grampian Mountains.*

The area has been intensely glaciated from the north-west.

FIELD RELATIONS.

(i) *The Lavas.*

The Lower Old Red Sandstone age of the lavas is adequately demonstrated by the surrounding and intercalated sediments, and the entire series may be placed with some certainty in Hickling's Carmyllie Group (2), the thickness of which is here, however, considerably over 2,500 feet. The flows are thus roughly contemporaneous with the Crawton Basalts of the Stonehaven area (3), and with the acid conglomerates, biotite-andesites, and dacites described by Dr. D. A. Allan (4), from the north of Forfarshire.

The upper flows are formed of a grey-black, compact and uniformly fine-grained basalt, which in its less fresh modifications becomes purple or reddish-brown in colour, due to the development of secondary products, especially haematite, by which the lavas are also stained in irregular streamers and veins. Veins of a bright red iron ore, with calcite crystals, have been obtained from planes of movement in the lavas. Only exceptionally are these upper flows porphyritic, in which case small olivine crystals, now decomposed, may be seen with a hand lens. Vesicular modifications are of very rare occurrence.

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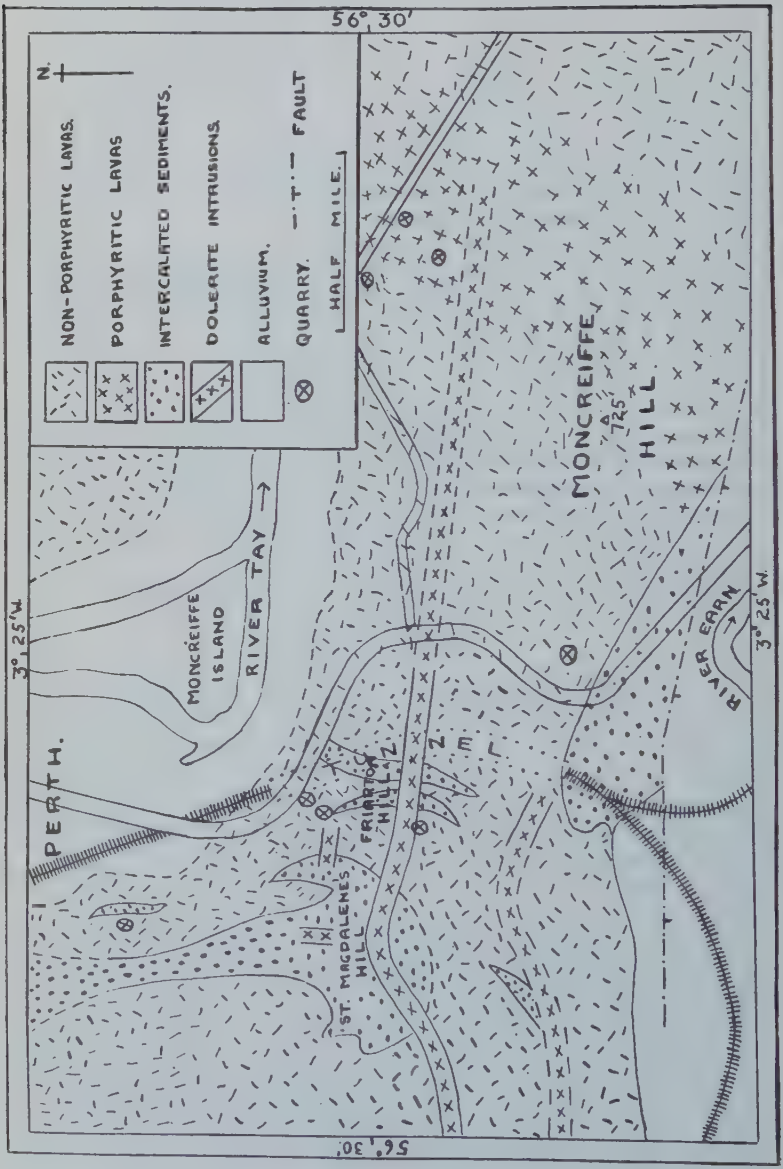
[1] Numbers in parentheses refer to papers in Bibliography.


56° 30′
N.
NON-PORPHYRITIC LAVAS.
PORPHYRITIC LAVAS
INTERCALATED SEDIMENTS.
DOLERITE INTRUSIONS
ALLUVIUM.
QUARRY.
FAULT
HALF MILE.
PERTH.
MONCREIFFE ISLAND
RIVER TAY
3° 25′ W.
MONCREIFFE HILL
725
FRIARTON HILL
ST. MAGDALENES HILL
Z
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L
RIVER EARN
3° 25′ W.
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The volcanic rocks have been extensively quarried in many places, and these cuttings, together with the numerous lava scarps, make the area rather better for petrological study than most of the Sidlaws proper, the geology of which I hope to deal with in the future. The grassy nature of the ground surface, however, does not allow measurements of the thickness of flows to be carried out, although in most cases this must be well over 40 or 50 feet, as walls of quarries are almost invariably composed of one flow. Exposures in quarries also demonstrate that considerable movement has taken place after consolidation.

In the large quarries situated on Toft Law and on Friarton Hill there is exposed a remarkable series of contemporaneous segregation veins, which are important in throwing light on the manner of differentiation of an Old Red Sandstone basaltic magma. They are pink in colour, with a curious saccharoidal appearance, and coarser in crystallization than the normal olivine-basalt of the quarry. Usually they extend to about half an inch in thickness, but rarely to over an inch, and they are arranged parallel to the surface of the flow. These veins are best developed at the south-east end of the quarry on Friarton Hill, where throughout the whole quarry wall one segregation after another may be traced, at intervals of about 8 inches. Branching and interbranching of two or more veins is not infrequent, while they are occasionally cut by veins of zeolites, of deuteric origin.

The basal series of the volcanic rocks, extending to about one-third of the entire thickness of the lavas, which is with the intercalated sediments considerably over 2,000 feet, contains several flows quite different in character. These rocks are always porphyritic with regard to felspar, and examples collected from the small quarries west of the Rifle Range and from the eastern scarps of Moncreiffe Hill proper show a remarkably large number of glassy labradorite phenocrysts, usually about 4 to 6 millimetres in length, set in a black fine-grained ground-mass.

Occasionally felspar phenocrysts nearly an inch long are visible.

The lavas of this lower horizon do not seem to have been erupted in as thick flows as the upper fine-grained rocks. Slaggy tops are frequently seen in the south-western scarps of the hill, very often containing, in the many-shaped vesicles, agates, calcite, and a green mineral, probably saponite or celadonite. Almost invariably these slaggy tops are decomposed, the black matrix changing to a dull red, and the felspar phenocrysts becoming kaolinized and sericitized.

In a lava-scarp about 80 yards south-west of the old curling pond on the top of Moncreiffe Hill, a series of beds is exposed which resembles the fine-grained black and purple lavas normal to the series but which contains a few sporadic felspar phenocrysts. These thus appear to form an intermediate group between the fine-grained and porphyritic lavas.

(ii) *The Intrusions.*

The east-west Permo-Carboniferous quartz-dolerite dykes which invade the lavas have been noted by Sir Archibald Geikie (5) and by Macnair (6). The former refers them to a Tertiary age.

The dykes do not differ in structural features or petrographic characters from the numerous Permo-Carboniferous quartz-dolerites of the Midland Valley of Scotland, around which so voluminous a literature has arisen. From considerations of space, therefore, no detailed account will be given.

Holocrystalline and tholeiitic types are both prominent, and there is an extensive development of acid segregations, squirts, and similar late differentiates resembling those described from other Scottish areas.

(iii) *The Sediments.*

The intercalated sediments form about 300 feet of the 2,000 odd feet of the bedded rock, and are best seen at three localities—at the northern and southern extremities of the railway tunnel, and on Tort Hill. The beds exposed at the northern entrance of the tunnel are coarse grits containing pebbles, mainly of acid andesite, up to four inches in diameter, intercalated with beds of a very fine shale, while at Hilton Junction, at the southern extremity of the tunnel, a red micaceous and felspathic sandstone, with occasional clay nodules, is exposed.

More variation is seen in the beds exposed on Tort and Friarton Hills, where the rocks vary rapidly from volcanic conglomerates with a distinctly ashy matrix, to normal coarse lacustrine sediments and thin seams of sandstone. The pebbles, even in the most ashy types, are invariably well rounded, and range in size from half an inch upwards to masses rarely attaining a foot in diameter. The sediments of this horizon are contemporaneous with the intercalated sediments exposed on Kinnoull Hill.

The most remarkable feature of these conglomerates is the occurrence in them of great numbers of fragments of igneous rocks much more acid than those with which they are intercalated. Probably in no case does the percentage of acid and sub-acid rocks reach less than 95 per cent, and in all the boulder analyses made, about 98 per cent of the specimens collected belong to such types. Only rarely may pebbles of basalt or Highland metamorphic rocks be recognized.

Undoubtedly the dominant rock-type, occurring as reddish-purple or pink pebbles, is a biotite-andesite with porphyritic felspars, while one specimen of a hornblende-andesite, the first yet recorded from the Tay Valley, has been sectioned. Other sectioned rocks are felsites resembling those of Peashill Point or Lucklaw Hill in Fife, and specimens petrographically indistinguishable from the oligoclase-biotite-porphyrite of Ninewells, Dundee. Only exceptionally are these water-worn pebbles in a fresh state of preservation.

The occurrence in many of them, however, of large prisms of apatite is worthy of notice.

Thin sedimentary veins also occur irregularly traversing the lavas of a few exposures. These differ quite appreciably in their minuteness of texture from the normal sedimentary inclusions, and examples collected from Friarton Quarry examined microscopically show a rather large development of irregular quartz fragments, with many minute augites, several flakes of brown pleochroic biotite and of muscovite, and a few particles of magnetite. There can be little doubt that these are fine muds, due to the disintegration of neighbouring volcanics and ashes, washed in among and picked up by the lavas, and their freshness may be explained by the shortness of the interval between their formation and consolidation. Other intercalations of a similar character are seen in a small quarry on the west side of the Rifle Range, where the largest band is 6 inches thick. This is so finely textured and so decomposed that no conclusive ideas can be drawn concerning its origin. It was first thought to be a thick, tachylytic squirt with a well-marked flow structure and now devitrified, but it seems more probable that it is a very fine banded mudstone. Pseudomorphs in haematite seemingly after mica flakes may be detected.

PETROGRAPHY.

(i) *The Lavas.*

The whole series of lavas is divisible into two main groups :—

(*a*) Microporphyritic olivine-enstatite-basalt.
(*b*) Olivine-enstatite-basalt with porphyritic felspars.

There is considerable variation, however, throughout the two types, which may be linked together by an intermediate variety containing a few felspar phenocrysts. The relative amounts of olivine and enstatite are subject to variation, in some flows olivine disappearing altogether, but mapping of these is prevented by the absence of adequate exposures. Minute variations in the texture of the groundmass more commonly serve as criteria for distinguishing one flow from another. The rocks are usually in a fresh state, but in a few cases specimens have been noted changed almost entirely to carbonates and iron ores.

Microporphyritic olivine-enstatite-basalt.

These are generally rocks with a very fine-textured uniform felspathic base, often possessing a marked flow structure. Not infrequently, however, an ocellar arrangement of felspar laths may be observed, while in a few types the groundmass tends to become glassy, although pitchstone-porphyrites like those of Dumyat (7) or Pitcullo (8) are never obtained. Many resemble closely the granulitic olivine-basalts of most Tertiary provinces, the groundmass containing monoclinic pyroxenes of extreme minuteness and slightly larger felspar laths, while phenocrysts of rhombic pyroxene and olivine form up to one-tenth of the rock.

The felspars show a complete gradation in size from the minute laths of the groundmass to the largest crystals, about 0·4 mm. in diameter, but only rarely are crystals obtained which can definitely be called phenocrysts. The crystals are usually uniformly idiomorphic, the larger being notably tabular, but in a few slides the felspathic groundmass forms an irregular grey matrix in which the other constituents are embedded. The felspars show persistent Karlsbad and albite, and rare periclinet winning, and range from acid to medium labradorite. The mean refractive index of central zones was found to be 1·560 ± ·002 and the maximum extinction angle 30°.

As recorded later, in some slides the occurrence of orthoclase with refractive index under Canada balsam has been detected.

Olivine.—No fresh olivine has been encountered, but all types of pseudomorphs, ranging from a variety in which the mineral is replaced by a pale green serpentine to crystals in which it is replaced entirely by dense iron ores, are found. The commonest alteration product is a serpentinous interior bordered by haematite which also permeates lamellar cracks and veins, but rare pseudomorphs in iddingsite have been observed. The olivine in most of the rocks occurs as small crystals, frequently showing bipyramidal terminations, with a length of about 0·3 mm., but larger crystals have been noted from the western end of the area, phenocrysts in an olivine-enstatite-basalt at Craigie Quarry attaining 2 millimetres in length. Glomeroporphyritic aggregates occasionally occur.

A second generation of olivines, minute in size and always pseudomorphed by iron ores, has been noted in a few rare cases.

Pyroxenes.—The rhombic pyroxenes are usually equidimensional with the olivines, and again are never definitely found fresh, although some shreds of pleochroic material may be hypersthene. The commonest alteration product is again serpentine, usually a pale pleochroic bastite variety with straight extinction, but the development of secondary iron ores has in some cases proceeded so far that one cannot recognize the characteristic outline of the crystal which is elsewhere so evident.

A second generation of pyroxene, in this case almost perfectly fresh, occurs, frequently to a very considerable extent, in the groundmass. These minute granular crystals are for the most part idiomorphic, and extinguish obliquely at angles up to 30°. They appear to be a variety of enstatite-augite. Rhombic pyroxenes do not occur in the groundmass.

Occasional delicate needles of apatite, magnetite grains and dust, and rarely (in one slide only), a flake of brown biotite form the accessory minerals.

THE SEGREGATION VEINS.

The segregation veins in Friarton and Magdalene quarries which have already been referred to, form the most interesting rocks in the area. They consist of analcite, felspar, and sparse ferromagnesians, with no olivine, but there are very considerable variations in the texture and amount of the constituent minerals. The bands in many cases graduate into the normal basalts, but frequently the junctions are sharply defined, yet showing no chilling.

The analcite occurs in patches sometimes attaining 3 millimetres in length, invariably interstitial to the surrounding felspars, and hence not showing crystal-outlines. It is isotropic, but frequently shows anomalous birefringence, and the refractive index, always much lower than the surrounding minerals and Canada balsam, has been found by the immersion method to be 1·484 ± ·002. The mineral is in general much fresher than the rather clouded felspar laths which surround it and from which it stands out clear and transparent, but in decomposed specimens it appears to have altered to calcite. Malachite green was readily absorbed in confirmatory staining tests after five minutes' treatment with hydrochloric acid. Many occurrences show a well-marked cubic cleavage.

Analcitization of the felspars in contact with the mesostasis is particularly evident. The distribution and habit do not suggest derivation from nepheline.

The felspars generally assume an idiomorphic tabular habit extending up to 0·6 mm. in length. Considerable variation in the nature of the dominant felspar exists throughout the rocks sectioned, segregations identical in the hand specimen occasionally differing widely under the microscope.

In the most alkaline slides the innermost parts of the crystals are frequently clouded with a fine brown dust, but occasional fresh portions, showing no albite lamellae, though rarely occurring in Karlsbad twins, have a refractive index found by the immersion method to be 1·522 ± ·002, and can be referred definitely to orthoclase. The outermost zones of these crystals have, however, a remarkable extinction for orthoclase, and the refractive index, found to be 1·528 ± ·002, refers them to a decidedly soda-rich type. Occasional crystals with this higher index are found showing in thin section a minutely fine albite striation. These may be considered to be anorthoclase.

In other sections anorthoclase is developed to a much greater extent, and there are also many felspars with well developed albite twinning, giving extinction angles of albite—acid oligoclase. Occasionally anorthoclase, orthoclase, and albite may be seen in the same slide. The albite seems more prone to iron-staining and decomposition than the other felspars.

The ferromagnesians are somewhat sparsely distributed throughout the slides of the segregation veins, in some much more so than others. The dominant mineral is a hornblende in elongated prisms and irregular granules, the prisms being idiomorphic towards the felspar and analcite. The mineral is faintly pleochroic from pale yellow green to pale brown green, has a mean refractive index 1·636 ± ·005, and an extinction angle $Z \wedge c$ of from 18°–25°. Specimens may be occasionally seen with a perfect amphibole cleavage, and some crystals are slightly zoned.

Fragments of biotite have also been observed, and other small crystals of rare occurrence, with an extinction angle of about 30°, seem to be referable to a soda diopside.

There is in many cases a large development of delicate needles of apatite, and iron ores in irregular outlines are abundant.

Zeolites have also been detected interstitially, and in thin thread-like veins permeating the segregations. The interstitial masses are co-existent with analcite in unaltered specimens, and no appreciable doubt of their primary origin can be entertained.

A partial analysis of one of the segregation veins from Friarton Quarry and the mode recorded by a Shand micrometer are as follows :—

Analysis.		*Mode.*	%
SiO_2	61·30	Felspar[1]	76
Na_2O	5·92	Analcite and Zeolitic Mesostasis	17·5
K_2O	3·96	Iron Ores	4·5
		Hornblende	2

Segregation in olivine-enstatite-basalt. Friarton Quarry, Moncreiffe Hill, Perthshire.

The occurrence of orthoclase and anorthoclase in these segregation veins invoked a more detailed study of the minute felspars of late crystallization, and of the groundmass of these lavas. As will be remarked later, the Geological Survey have recorded orthoclase-rich basalts or olivine-andesites from Taynuilt, and by permission of Dr. H. H. Thomas these slides (Survey Collection, Nos. 9628, 7409, 7408) have been examined.

The general microscopic appearance and texture of many of the microporphyritic Moncreiffe Hill lavas, and of the groundmass of the big-felspar lavas, very closely approximate to that of the analysed orthoclase-basalt of Taynuilt. Under a $\frac{1}{6}$th inch objective the groundmass of the latter is seen to consist, to a great extent of minute orthoclase laths, with microlitic augites, while the Moncreiffe Hill rocks, although not containing quite so high a proportion, do contain very considerable amounts of this felspar. The remaining two rather decomposed lavas in the Survey Collection from Taynuilt (7409, 7408), containing orthoclase, can also find their counterpart in the area, and there can be no doubt that a very close relationship exists between the lava-types of the two provinces.

Bright red zeolites or analcite in small vesicles, with a maximum length of 6 mm., arranged in bands about half an inch thick, which permeate the normal rock irregularly, may be seen in the south-east corner of Friarton Quarry. Under the microscope these are seen to be vesicular minerals, stained with haematite, the high refractive index of which they have adopted. They are frequently associated with, and apparently alter to, calcite. The normal rock in the neighbourhood of these bands is rather decomposed, irregular aggregations of carbonates, chlorite, and iron ore being particularly evident, while there is a large development of zeolitic mesostasis. Most of the felspars are zeolitized.

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[1] It has not been found possible to distinguish satisfactorily between the three felspars during measurement.

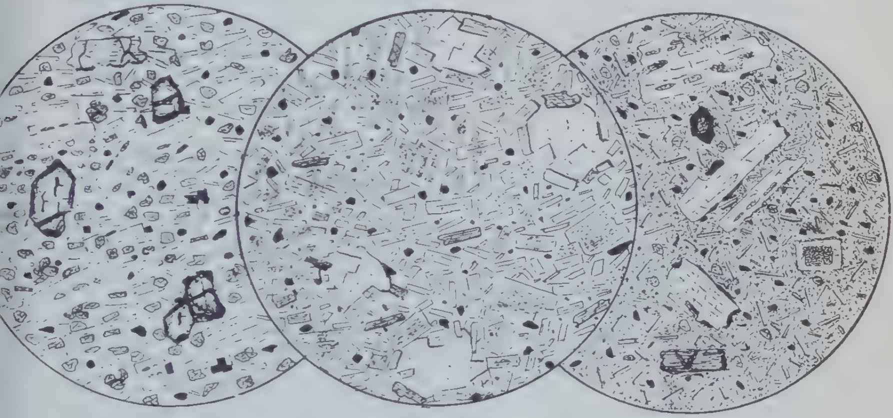

FIG. 2. FIG. 3. FIG. 4.

Micrographs of Lavas.

FIG. 2.—Olivine-enstatite-basalt from Craigie Quarry. Phenocrysts of olivine and enstatite in a matrix of labradorite, granular augites, and iron ores. The granulitic structure is characteristic. × 60.

FIG. 3.—Segregation vein in olivine-enstatite-basalt from Friarton Quarry. Laths of orthoclase, anorthoclase, and albite, occasionally clouded by haematite dust, with a few hornblendes, in a felspathic and analcitic matrix. The clear areas are analcite. × 60.

FIG. 4.—Olivine-enstatite basalt with porphyritic felspars, from the west of Moncreiffe Hill. The matrix is clouded by secondary iron ores. × 20.

(*b*) *Olivine-enstatite-basalts with porphyritic felspars.*

The lava type is characterized by porphyritic felspars of many sizes, but usually 4–5 mm. in length. These felspars show clear Karlsbad and albite, and in certain cases rare pericline twinning. They are frequently strongly zoned, the most basic varieties being medium labradorite, but crystals referable to andesine-labradorite have been observed. In some cases there are distinct traces of corrosion in the felspars, which are frequently concentrically honeycombed with glass. Inclusions of groundmass and especially of small pin-head augites are of common occurrence.

Porphyritic ferromagnesians do not exceed 1·5 mm. in length and are usually much less. The idiomorphic rhombic pyroxenes are again completely decomposed to serpentine and iron ores.

The matrix in which these porphyritic constituents are imbedded consists for the most part of minute felspar laths, referable to acid labradorite, showing Karlsbad and albite twinning. Occasional crystals of orthoclase have been observed.

The abundant ferromagnesian constituents of the groundmass are frequently pseudomorphed by iron ores, but small microlitic augites similar to those in the upper flows are in many cases undecomposed. Slightly larger idiomorphic pseudomorphs may also be observed, and there is a large development of interstitial chlorite, the origin of which is doubtful. Crystals of primary magnetite and small apatite needles form the main accessories.

PETROGENETIC CONSIDERATIONS.

Dr. C. N. Fenner (9) in some recent papers has shown that the crystallization of a basaltic magma leads to the formation of a residual glass rich in alkalies and iron, while Dr. F. Walker (10) indicates that in at least two cases this glass is of acid composition, equivalent to the micropegmatite of the Scottish Permo-Carboniferous quartz-dolerites.

These apparently anomalous results are of interesting application in the area under consideration. The Old Red Sandstone lavas of the Midland Valley, are, as a whole, characterized by the appearance of free quartz, both interstitially and as thin traversing veins, and it is therefore of great interest to find these highly alkaline unsaturated segregations in the same province. Quartz grains have been found in a few of the more decomposed segregation veins themselves, a phenomenon reminding one of the association of quartz and analcite in the quartz-dolerites of East Fife (11).

The Moncreiffe Hill segregation veins appear to be not unlike a type of contemporaneous vein found in the plateau lavas of Mull (12) and Ardnamurchan (13), formed of zoned laths of labradorite, analcite, augite, and aegirine-augite. The felspars of the Moncreiffe Hill segregations are, however, albite, orthoclase and anorthoclase, and the dominant ferromagnesian, sparsely developed, is a hornblende.

The detailed study of the petrology and petrography of the igneous geology of "Lake Caledonia", considered as a whole, has not yet been undertaken on as comprehensive a scale as has been done for the Carboniferous and Tertiary provinces, and many areas still await investigation.

It has been known for some time, however, that the Old Red Sandstone diorites, andesites, and basalts are decidedly richer in potash than the corresponding "average" rock in the tables of Osann or Washington, and it appears that the affinities of the entire group lie rather with the monzonites than with the true diorites, this being particularly evident in some parts of Argyllshire by the occurrence of kentallenites, appinites, monzonites, and diorites containing orthoclase. But such affinities in the lavas, although long suspected, are difficult to prove. Some rather decomposed Glen Coe lavas show considerable amounts of alkali felspar, while basic lavas, rich in orthoclase—possibly in some cases anorthoclase, as the crystals are too minute for adequate distinguishing tests—have been noted by the Geological Survey from the Taynuilt (14) and Lorne (15) areas. Orthoclase-olivine-basalts have been recorded by Professor E. B. Bailey from Taynuilt (15), and by Dr. F. Walker, from Ardsheal Hill (16). Specimens from both occurrences have been analysed.

Bailey notes that "there can be no doubt that a large proportion of Scottish olivine basalts of Lower Old Red Sandstone age come very close to the mugearites of Carboniferous and Tertiary times" (14).

Alkaline segregation veins are not recorded from any of the other Old Red Sandstone areas, and it is usually the case that the alkali-rich minerals are confined to an interstitial groundmass. The orthoclase evident in the norm may be referable there, or may be, to a limited extent, in solid solution in the acid plagioclase. We have here, however, clear evidence of a tendency for the differentiation to proceed towards a monzonitic type, and proof of the affinities of these Midland lavas to the kentallenites and other plutonics of the western province.

CONCLUSION.

No detailed comparison with the rocks of other areas will be attempted until an investigation of the rest of the Sidlaw Hills has been completed. The following salient points, however, have accrued from the present research.

(1) The lavas of Moncreiffe Hill are olivine-enstatite-basalts, several flows towards the base of the series showing porphyritic felspars. They are more basic than has hitherto been suspected, and are closely analogous to the Crawton basalts in Kincardineshire, and to the hypersthene-olivine-basalts of the succeeding Arbuthnot group (3), or the lavas of the Montrose centre (19). The published descriptions of the lavas around Dundee (17) and Tayport (18) show them to be dominantly andesitic, but it appears very probable that further investigation of the lavas of the Sidlaw Hills will prove that they are not andesites but are mainly referable to basaltic types.

(2) Previous to the formation of the basalts, effusion of acid andesites and injection of allied hypabyssals took place somewhere outside the area, giving rise to a land surface from which detritals were washed to Moncreiffe Hill. The close analogy of these results with those obtained by Dr. D. A. Allan (4) in the north of Forfarshire, and also by Dr. R. Campbell (3) in Kincardineshire must be remarked upon, as in that area evidence from conglomerates shows that highly

acid lava flows were probably the first to be erupted in Old Red Sandstone times and formed a cap over the Dalradian basement, denudation of which took place contemporaneously with the effusion of andesitic and basaltic lavas in order of increasing basicity. The sediments here are contemporaneous with the acid conglomerates of North Forfarshire and presumably also of Kincardineshire, and they doubtless represent the debris of these "Highland" acid lava flows.

(3) The lavas of the area show very close affinities with those of the Lorne plateau, and have been shown to contain orthoclase. Segregation veins rich in analcite and alkali felspar have been recorded.

In conclusion, I wish to express my gratitude to Dr. F. Walker and to Mr. D. E. Innes for their valuable advice and considerable assistance throughout this investigation, and I must also acknowledge my indebtedness to Dr. H. H. Thomas for the loan of H.M. Geological Survey slides of orthoclase lavas from the Lorne Plateau.

REFERENCES.

(1) Ami Boué. *Essai géologique sur l'Écosse*, Paris, 1820 (?), 142.
(2) G. Hickling. "The Old Red Sandstone of Forfarshire": Geol. Mag., 1908, 396.
(3) R. Campbell. "The Geology of South-Eastern Kincardineshire": *Trans. Roy. Soc. Edin.*, xlviii, iv, 1913, 923.
(4) D. A. Allan. "The Geology of the Highland Border from Tayside to Noranside": *Trans. Roy. Soc. Edin.*, lvi, i, 1928, 57.
(5) Sir Archibald Geikie. *Ancient Volcanoes of Great Britain*, ii, 1897.
(6) P. Macnair. *The Geology and Scenery of the Grampian Mountains*, ii, 1908.
(7) (Sir) J. S. Flett. "A Hypersthene Andesite from Dumyat": *Trans. Geol. Soc. Edin.*, vii, 1897, 290.
(8) D. Balsillie. "Note on a Hypersthene Andesite from Pitculla, Fifeshire": Geol. Mag., 1918, 346.
(9) C. N. Fenner. "The Residual Liquids of Crystallising Magmas": *Min. Mag.*, 1931, 539.
(10) F. Walker. "A Tholeiitic Phase of the Quartz-Dolerite Magma of Central Scotland": *Min. Mag.*, 1930, 368.
(11) F. Walker and J. Irving. "The Igneous Intrusions between St. Andrews and Loch Leven": *Trans. Roy. Soc. Edin.*, lvi, i, 1928, 12.
(12) H. H. Thomas and E. B. Bailey *in* "The Tertiary Geology of Mull, Loch Aline, and Oban": *Mem. Geol. Surv.*, 1924, 136.
(13) H. H. Thomas *in* "The Geology of Ardnamurchan, N.W. Mull, and Coll": *Mem. Geol. Surv.*, 1930, 114.
(14) E. B. Bailey *in* "The Pre-Tertiary Geology of Mull, Loch Aline, and Oban": *Mem. Geol. Surv.*, 1925, 114.
(15) E. B. Bailey *in* "The Geology of Ben Nevis and Glen Coe": *Mem. Geol. Surv.*, Sheet 53, 1916.
(16) F. Walker. "The Igneous Geology of Ardsheal Hill, Argyllshire" *Trans. Roy. Soc. Edin.*, lv, 1922, 147.
(17) J. W. Harris. "The Extrusive Rocks of The Dundee District": *Trans. Geol. Soc. Edin.*, xii, i, 1927.
(18) (Sir) J. S. Flett and H. J. Seymour *in* "The Geology of East Fife": *Mem. Geol. Surv.*, 1902, 386.
(19) A. Jowett. "The Volcanic Rocks of the Forfarshire Coast": *Quart. Journ. Geol. Soc.*, lxix, 1913, 459.

The Petrography of the Northern Portion of the Leinster Granite.

By Frank Smithson, Ph.D., F.G.S.

(PLATE XXXIII.)

INTRODUCTION.
THE ESSENTIAL MINERALS.
THE ACCESSORY MINERALS.
THE POSSIBLE EXISTENCE OF SEVERAL INTRUSIVE PHASES.
THE GRANITE AND ITS AUREOLE AS A SOURCE OF DETRITUS.

INTRODUCTION.

HAVING already published a brief description of the accessory minerals of the granite in the neighbourhood of Dublin (1928 [1]) it had been the writer's intention to make a study of the whole of the Leinster Granite giving special attention to the accessory minerals. As circumstances prevent the completion of this plan the following account has been drawn up, describing work done upon an area which extends from Dublin Bay to the neighbourhood of Aghavannagh, a distance of about 30 miles (compared with a range of 12 miles in the original paper) or nearly half the total length of the intrusion.

The following is a complete list of minerals recorded from the granite—essential minerals, accessory minerals, and minerals occurring in aplites and pegmatites associated with the granite.

Cubic	garnet, magnetite, pyrite.
Tetragonal . . .	anatase, rutile, zircon.
Orthorhombic . .	barytes, brookite, mispickel.[2]
Hexagonal-rhombohedral	apatite, beryl,[2] ilmenite, molybdenite (?), pyrrhotite,[3] quartz, tourmaline.
Monoclinic . . .	biotite, chlorite, epidote,[3] monazite, muscovite, orthoclase, spodumene,[2] titanite.[3]
Triclinic . . .	albite-oligoclase, microcline.
Amorphous or doubtful .	leucoxene, limonite, pinite, (and killinite).[2]

There are a few other minerals mentioned in the Geological Survey Memoir for the Dublin District (1903) as occurring in the granite which the writer has not been able to verify. These are: cassiterite, cerussite, corundum (?), fluorspar, hyalite, orthite (?).

THE ESSENTIAL MINERALS.

The granite is usually grey, although in places the tint is pink or buff, due to the coloration of the felspars. The rock consists of quartz, potash felspar (microcline or orthoclase or both), soda-lime felspar, muscovite, biotite (which is sometimes wholly or partially altered to chlorite) and a number of accessory minerals which will be described later.

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[1] Dates in parentheses refer to the list of works given at the end of this paper.

[2] In pegmatites or aplites.

[3] In the isolated granite intrusion of Aughrim.

The granite is usually regarded as an extremely uniform intrusion, and, indeed, samples indistinguishable from one another may be collected from widely separated localities. Nevertheless, variations occur, and a number of more or less distinct types may be recognized. For example, although much of the granite is even-grained, in some places large plates of muscovite are developed, whilst in others there are large crystals of microcline. Furthermore, measurement shows that the proportions of the essential minerals are by no means constant, the greatest variations being observed in the relative proportions of the micas. In the previous paper (1928) the writer stated that muscovite is always more abundant than biotite, but further observations show that this is not always true.

Measurements by means of the Shand micrometer on thirteen thin sections of granite from the area covered by the earlier paper showed that muscovite ranged from 1·1% to 18·4% by volume (average 8·5%), and biotite from 2·0% to 9·3% by volume (average 5·1%), whilst muscovite exceeded biotite in eight of the thirteen sections. Apatite, which was measured at the same time gave a mean value of 0·2% by volume.

It was noticed that the porphyritic granites which occur further south were rich in biotite, and measurements were made on four sections of such granite from the upper part of the Annamoe valley. Biotite exceeded muscovite in all four, the average percentages by volume being: muscovite 3·3; biotite 7·8.

A complete micrometric analysis of the granites of Ballybetagh and the Scalp was attempted with the results shown in Table I.

TABLE I. MINERAL COMPOSITION OF GRANITE.

		Ballybetagh.		*The Scalp.*	
	S.G. assumed.	% *by vol.*	% *by wt.*	% *by vol.*	% *by wt.*
quartz . .	2·65	38·8	38·9	35·6	35·5
soda-lime felspar.	2·64	31·7	31·6	29·1	28·8
potash felspar .	2·57	24·0	23·3	22·5	21·8
muscovite . .	2·8	1·1	1·2	6·1	6·4
biotite . .	3·0	4·3	4·9	6·4	7·2
apatite . .	3·15	0·1	0·1	0·3	0·3
		100·0	100·0	100·0	100·0

It is of interest to compare the above data with those obtained by Sollas (1889) and Haughton (1880). The method of Sollas was to draw the section by means of a camera lucida, determine the relative areas of the minerals present and convert percentage by volume into percentage by weight. Haughton based his calculations upon eight chemical analyses of the granite. Table II gives the percentages by weight.

TABLE II. MINERAL COMPOSITION OF GRANITE BY WEIGHT.

	Ballybetagh.	*Scalp.*	*Average of 13 Leinster Granites.*	*Three Rock Mountain (Sollas).*	*Average of 8 Leinster Granites (Haughton).*
quartz . . .	38·9	35·5	—	36·16	32·57
soda-lime felspar .	31·6	28·8	—	39·33	27·02 [1]
potash felspar . .	23·3	21·8	—	15·59	15·44
muscovite . .	1·2	6·4	9·1	8·93	19·16
biotite . . .	4·9	7·2	5·8		5·81
apatite . . .	0·1	0·3	0·25	—	—
	100·0	100·0		100·01	100·00

Sollas did not record separate figures for muscovite and biotite, but for the Three Rock Mountain granite the present writer obtained values as follows: muscovite 5·7%, biotite 3·8%, total micas 9·5% by weight.

THE ACCESSORY MINERALS.

In most of the examinations for heavy minerals samples weighing from 50 to 300 grams of the rock were employed. The rock was crushed to pass through a 40 mesh sieve (average aperture about 0·4 mm. square), washed, panned, dried, and treated with bromoform. Occasionally panning was omitted, but this resulted chiefly in an increase in the amounts of biotite and chlorite, and gave no advantage to justify the increased consumption of bromoform. The heavy residues from the bromoform separation were further subjected to electromagnetic separation and methylene iodide separation where necessary. Altogether eighty-five samples of granite were treated, and, for the purpose of recording the results in an abridged form, these have been classified in thirty-one groups according to locality. (See Table III, where the localities are arranged approximately from north to south.) Except where otherwise stated all samples were taken from solid rock in situ. In two localities, where exposures were scarce, samples of "growan" (granite weathered in situ to a soft rubble) were employed.

Apatite (Plate XXXIII, Nos. 21–8) is the most abundant accessory mineral in the granite, forming on an average about 0·25% of the rock by weight. It usually occurs in larger grains than the other accessories, and measurements in thin sections frequently exceed 0·5 mm. Residues from some of the finer grained granites contain complete crystals measuring less than 0·05 mm.

Most of the grains are clear and colourless, and, as found in the heavy residues, may be prismatic, rounded, or irregular. The angular grains must frequently be the result of the breaking of large crystals during the crushing of the sample, but an examination of thin sections shows that irregular grains occur in the rock itself. Rounded grains may be the result of re-solution, but it is noteworthy that even the grains which exhibit prism, pyramid, and basal pinacoid

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[1] Haughton calculated: albite, 22·10; silicate of lime, 4·92.

TABLE III. OCCURRENCES OF ACCESSORY MINERALS IN THE LEINSTER GRANITE.

	No. of Samples.	Anatase.	Apatite.	Apatite (dark-cored).	Barytes.	Brookite.	Epidote.	Garnet	Ilmenite.	Leucoxene.	Limonite.	Magnetite.	Molybdenite.	Monazite.	Pyrite.	Pyrrhotite.	Rutile	Titanite.	Tourmaline.	Zircon.
Kingstown	2	×	×	—	—	×	—	—	×	—	—	—	—	×	—	—	×	—	—	×
Dalkey	2	×	×	×	—	—	—	—	—	—	—	—	—	×	—	—	—	—	—	×
Killiney	5	×	×	×	—	×	—	—	×	×	—	—	?	×	—	—	×	—	—	×
Tibradden	3	×	×	—	—	—	—	×	—	—	—	—	—	×	—	—	—	—	—	×
Three Rock Mountain	5	—	×	—	—	—	—	×	?	—	—	—	—	×	×	—	—	—	×	×
Brenanstown (Cabinteely)	1	×	×	—	—	—	—	—	—	—	—	—	—	×	—	—	—	—	—	×
Laughanstown	3	×	×	—	—	—	—	—	×	—	×	—	—	×	—	—	—	—	×	×
The Dingle	3	×	×	—	—	—	—	×	×	×	×	×	—	×	—	—	—	—	×	×
Rathmichael	7	×	×	×	—	—	—	×	×	×	×	—	—	×	—	—	×	—	×	×
Ballycorus	2	×	×	×	—	—	—	×	×	—	—	—	—	×	—	—	—	—	—	×
The Scalp	7	×	×	×	×	—	—	×	×	×	×	×	—	×	×	—	×	—	×	×
Ballybetagh	2	×	×	×	—	—	—	—	×	—	—	—	—	×	—	—	—	—	×	×
Newtown	2	—	×	—	—	—	—	×	×	—	—	—	—	×	—	—	—	—	—	×
Glencullen Bridge	1	×	×	—	—	—	—	—	—	—	—	—	—	?	—	—	—	—	×	×
Glencullen Mountain	3	×	×	—	—	—	—	—	—	—	×	×	—	×	—	—	—	—	×	×
Kilmalin	1	—	×	—	—	—	—	—	×	×	—	—	—	×	—	—	—	—	—	×
Knockree	1	—	×	×	—	—	—	—	×	×	—	—	—	×	—	—	—	—	—	×
Balcoyl (Glencree)	1	×	×	—	—	—	—	—	—	—	—	—	—	?	—	—	—	—	—	×
Near Glencree Reformatory	1	—	×	—	—	—	—	—	×	—	—	—	—	×	—	—	—	—	—	×
Glassamucky (near Killakee Mt.)	1	?	×	—	—	—	—	—	—	—	—	—	—	×	—	—	—	—	×	×
*Shankill (W. of Kilbride)	1	—	×	—	—	—	—	—	×	×	—	—	—	×	—	—	—	—	—	×
Lough Bray District	6	×	×	—	—	—	—	×	×	×	×	—	—	×	—	—	×	—	—	×
*Kippure	2	×	×	—	—	—	—	—	×	—	—	—	—	×	—	—	—	—	—	×
Sally Gap District	3	×	×	—	—	—	—	×	×	—	—	×	?	×	—	—	×	—	×	×
Sally Gap to Glenmacnass	6	×	×	×	—	—	—	—	×	×	—	—	—	×	—	—	×	—	—	×
Glenmacnass Fall	1	—	×	×	—	—	—	—	×	×	—	—	—	×	—	—	×	—	—	×
Upper Annamoe Valley	2	×	×	—	—	—	—	—	×	—	—	—	—	×	—	—	—	—	—	×
Near Lough Tay	2	—	×	—	—	—	—	×	×	×	—	—	—	×	—	—	—	—	×	×
Glenmalur	1	—	×	—	—	—	—	—	×	—	×	—	—	×	×	—	—	—	—	×
Near Aghavannagh	3	×	×	×	—	—	—	—	×	×	—	—	—	×	—	—	×	—	—	×
2 miles S.W. of Aghavannagh	3	×	×	—	—	—	—	×	×	×	×	—	—	×	—	—	—	—	—	×
Aughrim Intrusion	2	—	×	—	—	—	×	—	—	—	—	—	—	—	×	×	—	×	—	×

do not usually show such sharply defined facets as are seen on the apatite grains from certain other granite. In the finer grained granites (e.g. at Glenmacnass Fall) unbroken prismatic grains occur in the greatest abundance.

The apatite is often cloudy, and in some samples there is definite evidence of corrosion. Inclusions of zircon are frequent, and in some of the residues the grains are crowded with minute zircon crystals. Cavities, which often contain gas bubbles in liquid, are common in some of the larger apatite grains.

In the earlier paper reference was made to a feebly magnetic variety of apatite in the granite of the Dingle (1928, p. 14). No further occurrences have been observed. Another variety already described, namely, dark or dark-cored apatite (1928, p. 14; 1931, p. 133; also Fleet and Smithson, 1928) has been found in many of the samples. Where pleochroism is observed the mineral is darkest for the fast ray. Typical examples of these grains are illustrated (Plate XXXIII, Nos. 24 and 26), and one unusual type which has a zonal structure (Plate XXXIII, No. 25).

Anatase (Plate XXXIII, Nos. 10–12) is widely distributed, but except in a few samples, e.g. from Dalkey and Killiney, it is not abundant. Well formed crystals are scarce, but of the two habits in which crystals occur, tabular and bi-pyramidal, the former is the more common. Most of the grains, however, are irregular or show outlines only partly determined by the crystal facets. The colour is blue, yellow, or whitish. The largest grains measure about 0·2 mm.

Brookite.—In the previous paper the occurrence of a few small plates of this mineral in the granite of Killiney and Dalkey was recorded. No further occurrences have been observed.

Epidote.—Grains of almost colourless epidote occur in the Aughrim granite, but not in the granite of the main chain.

Garnet is met with in a few of the heavy residues, being either entirely fragmental or consisting of broken faceted grains showing the forms {211} and {110} in combination. The grains, which are pale pink in colour, are often as much as 0·3 mm. in diameter.

Ilmenite and leucoxene.—Ilmenite is present in many of the samples, but rarely forms a considerable portion of the heavy residue. The grains are usually small (0·05 mm. to 0·25 mm.) and rounded, but occasionally platy in habit. Partial or complete alteration to leucoxene is observed.

Limonite occurs in some of the more weathered samples and occasionally is pseudomorphous after pyrite.

Magnetite.—Rare occurrences of this mineral have been recorded during the examination of the unmounted residues, but octahedral grains, such as occur in some granites and are readily recognized in slides, appear to be entirely absent.

Molybdenite.—Granite samples from Killiney and Sally Gap area have yielded two grains with a silvery metallic lustre. Chemical examination has not been attempted, but it is believed that the grains may consist of molybdenite.

Monazite (Plate XXXIII, Nos. 13–20).—In the earlier paper reference was made to the abundance of monazite. This mineral is most easily recognized in the mount by its yellow colour when viewed by reflected light, whilst the absorption spectrum and the ammonium molybdate test for phosphate afford ready confirmation of its identity. Although in many of the residues the grains are ovoid, some of the samples yield grains which show evidence of crystal form. Grains measuring from 0·15 mm. to 0·20 mm. in length and 0·10 mm. to 0·15 mm. in width are common, whilst one from the granite of Newtown measured 0·52 mm. × 0·33 mm. Monazite frequently contains small, elongated zircon crystals, which may often be seen projecting from the monazite grains.

Although difficult to detect in thin section, monazite has been observed and confirmed spectroscopically in a section (about 60 microns in thickness) of granite from Knockree. The monazite, which has an inclusion of zircon, occurs in biotite and is surrounded by a halo.

Pyrrhotite and pyrite occur together as angular fragments in the granite of Aughrim. Using a magnet and an electromagnet it was not possible to effect a perfect separation, and it is likely that many of the grains consist of a mixture of the two minerals. Pyrite has also been observed in residues from the granite of Glenmalur and the Scalp.

Rutile is a rare constituent. The grains, which rarely exceed 0·2 mm. in length, are yellow or dull brown, and either lath-shaped or stumpy prisms. Aggregates of fine acicular crystals occurring in chlorite probably consist of rutile.

Titanite (*sphene*).—In the previous paper the writer stated that this mineral did not occur in the Leinster granite or in the sands derived from it. This observation was in keeping with the generalization made by Dr. Mackie (1928) that monazite-bearing granites usually contain no titanite. Subsequent work has failed to reveal this mineral in the granites of the main chain, but one perfect crystal has been found in granitic sand near Kippure, whilst abundant titanite was found in a dark biotite-bearing pebble from a stream bed south of Sally Gap, where the altitude (1,450 feet) and position exclude the possibility that the pebble may have been carried from outside the Leinster Granite area.

In the Aughrim granite, titanite is common and appears in the residues as irregular grains, often showing pleochroism from pink to colourless.

Tourmaline occurs in some localities as a fairly abundant accessory. In the heavy residues it usually consists of angular fragments of a brown or greenish brown colour. The blue tourmaline which occurs in some of the aplites has not been observed in the granite.

Zircon (Plate XXXIII, Nos. 1–9) is present in every sample examined. In the area dealt with in the previous paper, zircon is never abundant, but it occurs in relative abundance in residues from fine-grained granites near Aghavannagh, in Glenmacnass and elsewhere. The length rarely exceeds 0·20 mm. and the ratio of length to breadth averages about 4 : 1. Imperfect zoning is fairly common, but in crystals from granite at Aghavannagh (No. 7) the structure is well developed. In some of the crystals (e.g. Nos. 1 and 9) there is a suggestion of growth in stages upon an original rounded grain.

THE POSSIBLE EXISTENCE OF SEVERAL INTRUSIVE PHASES.

Kinahan (1878) suggested that the Leinster Granite consisted of two intrusive phases, without defining clearly the two types of granite which his suggestion implied. He wrote :—

> " In this range of hills there are evidently granites of two distinct ages partly jumbled up together and hard to separate on account of the paucity of sections, also because some of the characters of the different rocks are so much similar. In both there is the ' grain ' that makes them capable of being split easily into long blocks. The older granite, however, seems to be a better stone than the later, as the later usually weathers deeply either getting rusty or changing to growan. Becoming growan is not solely a character of the later granite, as in the main range some of what seems to be the older granite is thus weathered."

The present writer is of opinion that the granite cannot be a simple intrusion but that any attempt to distinguish the definite phases must at present be purely tentative. The problem is complicated by the fact that in some areas the original structures of the granite are altered by shearing. Nevertheless, what may be described as two extreme types can be recognized.

(*a*) *Felspar-porphyritic granite.*—This type is well developed in the upper part of the Annomoe valley, also near Sally Gap and near Aghavannagh, whilst some of the sheared granite of the Scalp may perhaps be referred to the same type. The conspicuous features of the rock are the large crystals of microcline, and the presence of biotite in greater abundance than muscovite. The heavy residues are relatively large and contain much ilmenite, monazite, and zircon, whilst tourmaline is usually absent (see Fig. 1, A). The rock is generally compact and unweathered. This is probably the older granite.

(*b*) *Muscovite-porphyritic granite.*—This type is exemplified by the granite of the Three Rock Mountain, the Dingle and Laughanstown. Muscovite which is more abundant than biotite, occurs as large hexagonal plates. Some even-grained granites, e.g. in the Glencullen area, which contain much muscovite should probably be referred to this class. The heavy residues are relatively small and consist mostly of apatite (see Fig. 1, B) ; tourmaline is commonly present. The rock weathers readily. This is probably the newer of the two types.

The reason for assuming that type (*b*) is the younger are as follows : (i) The abundance of muscovite and tourmaline imply

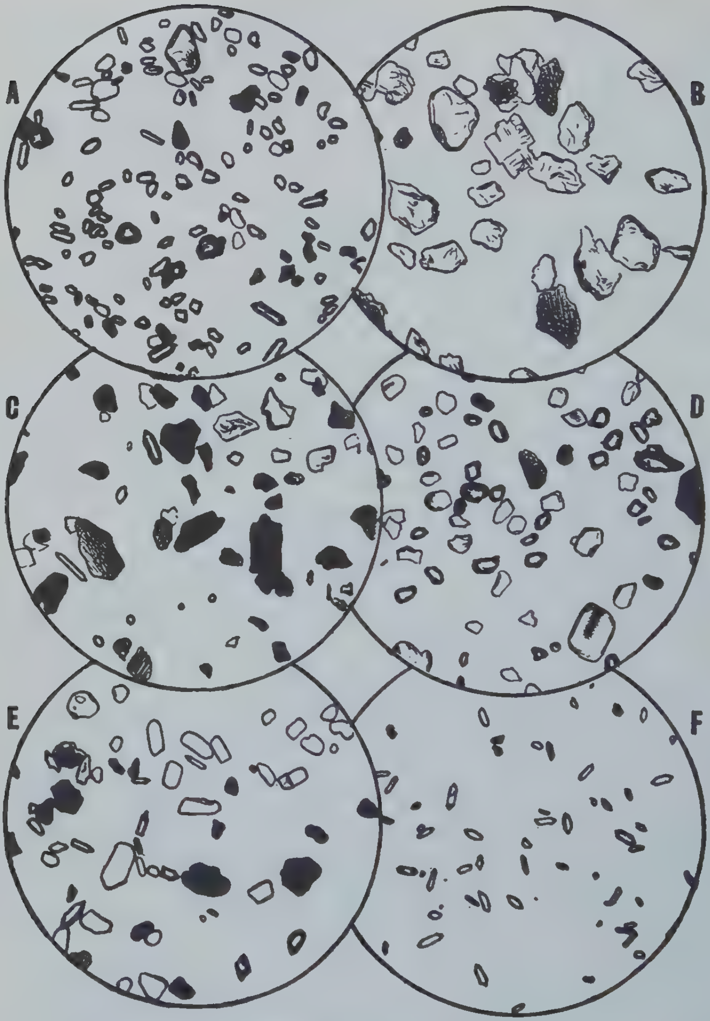

FIG. 1.—Assemblages of Heavy Minerals from the Leinster Granite. Magnification × 33.

	Locality.	*Minerals present.*
A	Aghavannagh . .	Ilmenite, apatite, monazite, zircon.
B	Glencullen Bridge . .	Chiefly apatite.
C	S. of Sally Gap .	Ilmenite, zircon, biotite.
D	Ballybetagh . . .	Apatite, ovoid monazite, ilmenite.
E	Glenmacnass . .	Ilmenite, apatite, zircon.
F	E.N.E. of Aghavannagh	Chiefly zircon.

the presence of much water and other late volatile constituents. (ii) The heavy residue of type (*b*) is intermediate between that of type (*a*) and that of the aplites, which are clearly later than the granite. Type (*a*) contains the largest amount of the minerals which crystallize early (zircon, monazite, ilmenite), whilst in the aplites these constituents are scarce.

It is certain that much more light could be thrown upon this problem if accurate chemical analyses of carefully identified types were available.

THE GRANITE AND ITS AUREOLE AS A SOURCE OF DETRITUS.

The assemblage of minerals present in the Leinster granite is sufficiently characteristic to be distinguished from that of many if not all other British granites. Yet the possibility of identifying Leinster granite minerals when they occur in sediments cannot be claimed with confidence. There is no doubt that comparison would produce more trustworthy results if made with actual material than if reliance were placed upon descriptions or illustrations alone. As already pointed out, the heavy residue from the Leinster granite is usually small in amount, somewhat fine-grained, and often composed largely of the unstable mineral apatite, so that in a sediment derived from various sources the Leinster granite minerals might be outnumbered by those from less extensive areas of denudation.

A study of the rocks of the aureole shows that the schists contain a large proportion of heavy minerals, particularly biotite, tourmaline, garnet, hornblende, and ilmenite,[1] and it is evident that these rocks must have been a more important source of heavy minerals than the granite, especially during those periods when the granite was much less deeply denuded than it is to-day. Furthermore, the aplites and pegmatites, although forming only a small proportion of the rock mass, must have supplied relatively large amounts of garnet and tourmaline. The characteristics of these minerals may, however, afford some indication of their source.

Tourmaline from the schists almost always consists of small but somewhat elongated grains determined by the prism faces, whilst that from the igneous rocks is usually irregular. The prisms of tourmaline in the igneous rocks are larger than in the schists, so that the shape of any small grains produced from them, whether by laboratory or by natural processes, will be determined more by fracture and cleavage than by crystal form. As found in the schists this mineral commonly contains cavities and black irregular inclusions similar to those in the garnet, andalusite, and staurolite; tourmaline from the igneous rocks is remarkably free from inclusions, and cavities are not common. Tourmaline from the aplite is often bluish, but in the schists and granite only brownish tints have been observed.

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[1] Other heavy minerals present are: andalusite, apatite, chlorite, magnetite, pyrite, pyrrhotite, rutile, staurolite, and zircon.

Garnet from the metamorphic rocks usually consists of irregular or roundish grains, and when faceted crystals are seen the form present is {110}. Garnet in residues from the igneous rocks consist commonly of clear faceted grains showing a combination of {211} and {110}, or splinters of larger crystals. Garnet from the schists often contains dark inclusions, and the grains are frequently cloudy.

In conclusion the author wishes to thank the Trustees of the Dixon Fund for a grant in aid of this research.

REFERENCES.

1928. Fleet, W. F., and Smithson, F. Geol. Mag., LXV, 6–8.
1880. Haughton, S. *Jour. Roy. Geol. Soc. Ireland*, v, n.s., 43.
1878. Kinahan, G. H. *Manual of the Geology of Ireland*, 197–8.
1928. Mackie, W. *Trans. Edinburgh Geol. Soc.*, xii, 1, 23.
1928. Smithson, F. Geol. Mag., LXV, 13–16.
1931. —— *Proc. Geol. Assoc.*, xlii, 133.
1889. Sollas, W. J. *Trans. Roy. Irish Acad.*, xxix, 489.

EXPLANATION OF PLATE XXXIII.

Mineral Grains from the Leinster Granite.

Zircon (magnification 190). 1. Near L. Tay. 2. Glenmacnass. 3. Glenmalur. 4. Knockree. 5–7. Near Aghavannagh. 8–9. Near Sally Gap.

Anatase (magnification 190). 10. Dalkey. 11. Ballybetagh. 12. Killiney.

Monazite (magnification 190). 13–14. Ballybetagh. 15. Kilmalin. 16. Near Aghavannagh. 17. Near L. Bray. 18. The Scalp. 19. Near L. Tay. 20. Ballybetagh.

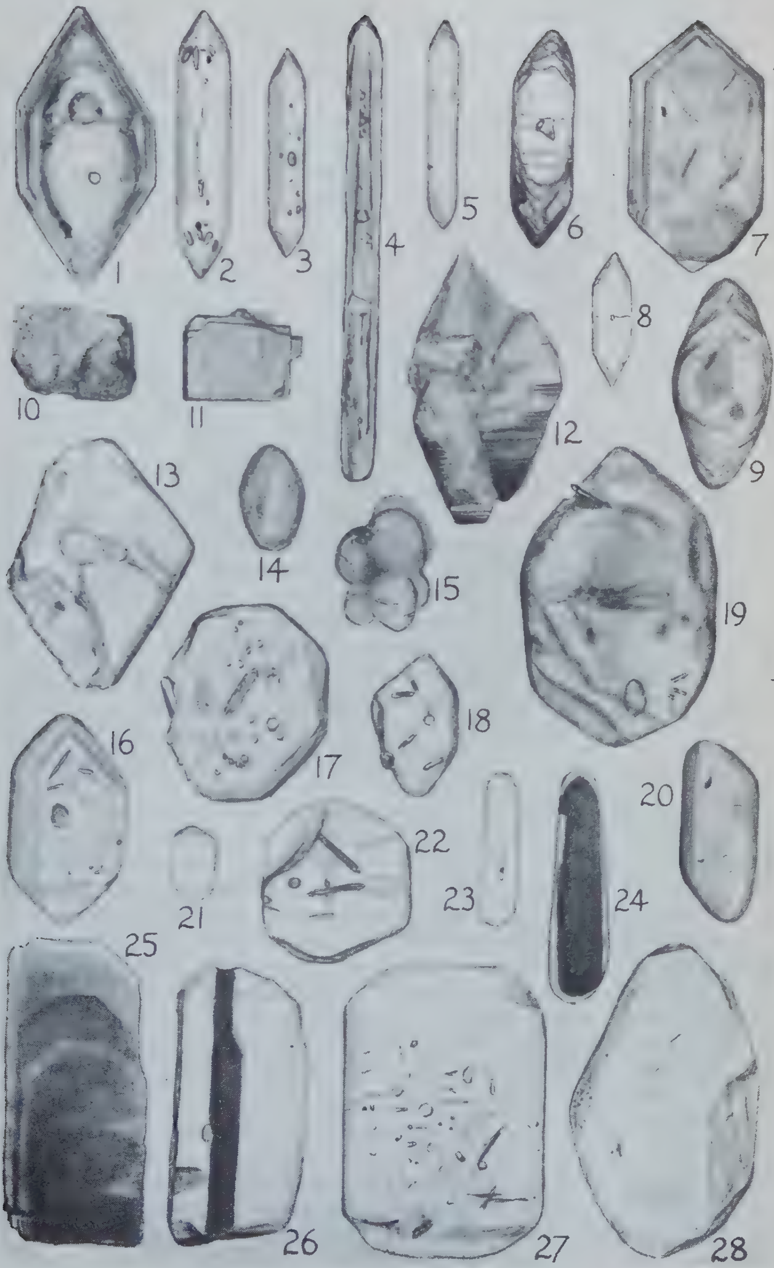
Apatite (magnification 116). 21. Glenmalur. 22. Seapoint (Kingstown). 23. Glenmacnass. 24. Rathmichael. 25. Ballybetagh. 26. Near Sally Gap. 27. Near L. Bray. 28. Three Rock Mt.

A Peneplain and Re-excavated Valley Floors in Dorsetshire.

By Ernest St. John Burton, F.L.S., F.G.S.

THE geological formation in the district around the ancient village of Worth Matravers (Geological Survey Map, "Swanage," Sheet 343), situated about ¾ mile from the Dorset coast, consists of Lower and Middle Purbeck Beds (Upper Jurassic). A considerable portion of these beds has been removed by denudation, with the result that the Upper Purbeck division has not been preserved near the coast, except westward at Worbarrow Bay and Lulworth Cove, and eastward at Swanage, the exposures at these localities being due to the high northerly dip. The Portland Stone immediately underlying the Purbeck Beds forms a line of inaccessible sea-cliffs extending from Winspit, one mile south-south-east from Worth Matravers, to Durlston Head, 4¼ miles in a direct line eastward.

If a transverse section is drawn from Challow Hill at Corfe Castle to St. Aldhelms Head, i.e. from north to south, the structure of the strata shows that the steep northerly dip diminishes almost to horizontality between Kingston and St. Aldhelms Head. A south



HEAVY MINERAL GRAINS FROM THE LEINSTER GRANITE.

[*To face p. 474.*

or south-easterly dip sets in, and although the terrain remains relatively high up to 500 feet between Kingston and Hounstout Cliff on the coast, there is a gradual slope eastward until the south-easterly dip becomes so pronounced that it results in carrying the Jurassic Rocks near Swanage far beneath the English Channel.

The steeper northerly dip reaches the coast again in the vicinity of Peveril Point, but the angle of inclination is less. The long descent of the "Green" marks it well, and forms a good example of a dip-slope. The crustal movements to which the final tilting of these strata was due belong to the Post-Cretaceous disturbances, and as such are not of earlier date than the Miocene.

The area that claims present attention extends from Durlston, on the east, to Worth Matravers, Kingston, St. Aldhelms Head, and Hounstout at Chapmans Pool on the west. The whole of it lies south of the long valley excavated in the Wealden, from Swanage to Worbarrow, and its position can be clearly traced on a contoured map. Apart from being geologically described in the Survey Memoirs on this district ("The Geology of the Isle of Purbeck and Weymouth", *Mem. Geol. Surv.*, 1898, and "Guide to the Geological Model of the Isle of Purbeck", *Mem. Geol. Surv.*, 1906) by the late Sir Aubrey Strahan, it is not alluded to otherwise than as a high plateau. From a favourable vantage point on the upland, especially if taken near the coast, the observer will notice the markedly flat surfaces shown by the prominences of St. Aldhelms Head (354 feet), the adjacent Emmit Hill (400 feet), Hounstout (501 feet), and around Encombe, but not immediately approaching the coastal edge of this region. If the view is continued so as to embrace the fine extent of coastline between Winspit and Durlston Head, the same level tops characterizing all the higher ground are clearly discernible when visibility is good, the general impression being far more striking in the field than if described in words. Now, although this coastal upland appears at first sight to present the usual topographical features of a plateau, it really possesses certain distinctive characters that seem sufficiently emphasized to justify its definition as a peneplain, or plain of denudation. The wholesale bevelling-off or complete elimination of all harsh contours and rugged projections in the hill-sides, and the long flat-topped prominences divided by much worn coastal valleys, all lend support to the view that the upland from Durlston to Worth Matravers and beyond this, constitutes a peneplain, or the remnants of one having at an earlier period, but subsequent to the lowering of the crest of the anticline, a somewhat wider extent northward and an incomparably greater extension southward.

An enormous thickness of superincumbent strata which may be estimated to have reached nearly 5,000 feet, assuming that the approximate thicknesses of the newer formations were maintained over the anticlinal area in its original integrity, was removed during the prolonged denudation following Post-Oligocene earth-movements.

There is reason to believe that the later erosional phases affecting the upland were accomplished towards the close of the glacial period. These are here treated as relevant to the formation of the peneplain and the valleys intersecting it, although this statement is not intended necessarily to imply the embodiment of an ice-sheet in Dorset. It is, however, probable that climatal conditions at the time that the valleys were formed involved extreme rigours of cold and heavy snowfall.

Evidence of ice-action in the shape of *striae* on rocks or scratched stones would be readily destroyed, having regard to the easily disintegrated surface of so much of the limestones. Chert-bearing beds of the Purbeckian might have offered more resistance to the abrasive pressure of ice, but have been largely removed from the denuded surface in the Isle of Purbeck itself, and the remaining beds of Purbeck age are deeply weathered to 6 feet and more below the surface, so as to resemble a breccia rather than ordinarily stratified rock. Actual proof of the glaciation of Dorset is somewhat obscure, yet Dr. Colley March, F.S.A. (W. Colley March, "Dorset during the Glacial Period," *Proc. Bournemouth Nat. Sci. Soc.*, ii, 1900, 71–85) has brought forward some cogent arguments although not absolutely convincing evidence, having the tentative support of Osmond Fisher and several other geologists of repute, in favour of such a theory which eventually may not be lightly laid aside.

It now remains to consider the valleys whose present openings are situated along that portion of the coast under review. Their similarity of form, due to the re-excavation of the relatively shallow floors, is very striking when compared with the chines of Bournemouth in the adjacent county of Hampshire, and their origin is identical in character if not in age. The process of formation of the Bournemouth chines has been described by Bury (H. Bury, "The Chines and Cliffs of Bournemouth," GEOL. MAG., LVII, February, 1920, 71–76). In Dorset, these are strike valleys traversing the peneplain and leading by somewhat winding courses down to the edge of what are now marine cliffs. The valleys are necessarily short for the reason that they represent merely the upper portions of longer valleys which were in existence before the encroachment of the sea upon the present coastline. High ground lies close in their rear, whence a southerly drainage, the remnants only surviving at the present day, originally flowed to a broad main valley, transverse to them but now occupied by the English Channel.

These comparatively short valleys in all probability extended at a former period much farther south, and were tributary to the principal valley mentioned, but they have been truncated by the successive cutting-back of their more southerly parts, and also by the slow process of coast-erosion. They must perforce become shorter still, since the rate of their recession, inland, is reduced to a minimum, and the amount of wastage along their flanks is almost negligible. All the evidence points to a nearly quiescent stage as regards erosion compared with its far more active phases during the past. Subsequent developments in the topographical history of this region are exemplified by the re-excavation of the floors of the valleys near the coast. Small streams emerging as springs at the head of these are sufficiently active agents for the consummation of that work. It would be an error to suppose this form of erosion, i.e. the re-excavation of the valley floors, to be an inevitable process following without break the initial formation of depressions of this character, and to be penecontemporaneous or nearly so; the secondary effects of epigene action have, in the district around Worth Matravers, been determined by two operative causes widely separated in point of time.

The first of these was initiated by upheaval of the land, and the ensuing formation of basin-shaped shallow valleys whose direction was determined by the lines of drainage maintained during the earlier stages of the upland.

The second was due to subsequent geographical changes resulting in the invasion, by the sea, of the ancient southern valley. The recession of the coastline then continued so far that the openings of the shorter valleys came to be truncated by the advance of the sea, and in such a manner that the ancient floors contemporaneous with the early form of the valleys were approached by an increasingly steeper gradient at the seaward end. Thus, a renewal in activity of the streams that trenched them took place, and caused the centre of the floors to be lowered more rapidly than the sides. Hence the earlier floors were cut through, and now have the appearance of terraces on either side of rather deep and especially narrow ravines. The process of excavation is naturally better aided if the rock stratum is less durable than that above, as at Chapmans Pool, where the Kimmeridge Clay being the lowest formation has been cut through to a depth estimated at about 50 to 60 feet below the original valley floor.

REVIEWS.

GEOLOGICAL MAP OF THE COMMONWEALTH OF AUSTRALIA. By Sir P. EDGEWORTH DAVID. Scale 1 : 2,990,000. In 4 parts. 42 × 34 in. London: Edward Arnold & Co., 1932. Unmounted with volume of Explanatory Notes (pp. 177), 20*s.* net; each part in 28 sections, mounted on linen, in case with volume of Explanatory Notes, 42*s.* net.

THE publication of a new geological map of Australia by Sir Edgeworth David marks an important stage in the progress of regional geological research. No one could have been more fitted for the task. Sir Edgeworth David's personal researches have covered an amazingly wide field, embracing geological problems in every state of the Commonwealth, and through half a century he has by extended travel become familiar with the field work of his geological colleagues in every corner of the Continent.

Since his retirement from the Chair of Geology at Sydney in 1924 he has made the production of this map and the writing of the *Geology of the Commonwealth* his unremitting task. The firstfruits of this labour of love are revealed in the map with the volume of Explanatory Notes before us. The map itself, a beautiful work of art in more than twenty colours and seventy-six different printed signs, is a triumph of lithographic skill, reflecting great credit on the Government lithographer, Mr. S. G. Miller, of the Department of Lands, Sydney. Mounted as a wall-sheet it measures roughly 6 by 5 feet, and the scale (48 miles to the inch) forms a very convenient one for reference to geological details. Papua, the Mandated Territory of New Guinea, and part of the Solomon Islands are included, while a special inset reproduces the geological detail of Tasmania on a scale of 24 miles to the inch.

Here is represented the accumulated geological knowledge of nearly a century of research by State geological surveys and private workers, including much hitherto unpublished.

The great task of correlating and co-ordinating this ever-increasing mass of data has been accomplished by the author almost single-handed. The great advance in geological knowledge is made apparent when comparison is made with the earlier geological maps of the Commonwealth that are available. Geologically unexplored areas are left uncoloured, and apart from large tracts in New Guinea are now principally confined to Central and Northern Australia. The interpretation of the geological structure is materially aided by eleven marginal sections. These will be found of great service by students, though their vertical scale has had of necessity to be greatly exaggerated.

The Explanatory Notes which accompany the map represent a much-condensed summary of the three-volume *Geology of the Commonwealth,* still in preparation. They include a detailed description of the marginal sections of the map, and are themselves illustrated by sections. Numerous tables of correlation accompany the description of the geological formations, while a condensed account of the Cainozoic geology of New Guinea assembles and co-ordinates data from rare publications, many of which are inaccessible to students.

In an eloquent concluding chapter to these Notes the author, with rare insight, surveys the fundamental changes which have operated in the Australasian region since Archaean time.

The geological public the world over will wait expectantly the detailed description and analysis of the geological framework of the Commonwealth of which these Explanatory Notes are but a foretaste.

C. E. T.

PETROGRAPHY AND PETROLOGY. By FRANK F. GROUT. pp. 552, figs. 266. New York: McGraw-Hill Book Co., 1932. 30*s.* net.

THE plan of this book is simple. The petrography and petrology of the three subdivisions of rocks are described and discussed in six successive chapters, and a concluding section includes sets of mineral tables and a selected list of literature on the topics referred to in the text. As might be expected, the space devoted to the igneous rocks (231 pp.) is much greater than that reserved for sediments (90 pp.) or metamorphic rocks (93 pp.). The petrographic sections are, on the whole, well done, but take too much the form of notebook summaries.

It is refreshing to find that the author does not elaborate a new classification and nomenclature of igneous rocks peculiar to himself. The scheme chosen is simple and readily adapted from the commonly accepted Rosenbusch system.

Amongst common rock names renderings such as " granophyr " and " trachite " appear unnecessary. Porphyrite as a rock name with a distinctive meaning is not " nearly obsolete " as the author pretends. In the sections on the sediments too little attention is devoted to elutriation methods, and a fuller discussion of the interpretation of heavy residues in correlation would have been welcome. A modern discussion of oölites and bedded iron ores deserves a place in a chapter on the petrology of sediments, but is wanting here. In the petrography of the metamorphic rocks, the notebook style of the text is even more apparent than in the preceding sections. The significance of the crystalloblastic series, and particularly the time of origin of porphyroblasts (referred to as metacrysts), has proved a stumbling block to the author, as it did to Van Hise and Leith. An amazing amount of fact, speculation, and hypothesis is covered in the petrological sections, which are free from laboured view points.

To the reviewer it appears that the book suffers from overtabulation and insufficient critical discussion of the legion of facts and hypothesis which are given in the text. For the elementary student there is lack of guidance among a multitude of hypotheses. Numerous photographs and text-figures serve to illustrate the topics discussed. Some of the figures, however, are barely mentioned or given quite inadequate discussion in the text (cf. figs. 75, 82, 166).

Clearly the book is more suitable for advanced students who have already profited by a systematic course of lectures. It should find a home in every working library.

C. E. T.

THE GENESIS OF THE DIAMOND. By ALPHEUS F. WILLIAMS. 2 vols. pp. 636, pls. 221. Ernest Benn, Ltd., 1932. Price £4 4*s.*

THE handsomely printed volumes before us represent the fruit of more than thirty years' study and experience of the occurrence of the diamond. The author, as general manager of the De Beers

Diamond Mines, has had unrivalled opportunities for the pursuance of these studies, and his researches represent signal contributions to the knowledge of the diamond. The first volume opens with authoritative chapters on diamond mining practice and the geologic setting of the kimberlite pipes. These are followed by sections devoted to the petrology and origin of kimberlite, together with an exhaustive treatment of the accidental and cognate inclusions. In these chapters the author is prone to over-quotation from the works of other investigators at the expense of conciseness and clarity. A detailed account of the morphology of the diamond is given with many new observations, illustrated by a set of beautiful photographs of the surface features of the crystals. In an all too brief section devoted to the origin of the diamond the view is expressed that the diamond crystallized from the kimberlite magma at depth, beginning first in the cognate inclusions as the igneous eclogites. The last chapter gives an account of the diamond-bearing alluvial gravels of the Union of South Africa. Throughout, the book is profusely illustrated, some of the plates, such as the photomicrographs of kimberlite and its inclusions, being reproduced in colour. The study is enriched by many new analyses of kimberlites, eclogites, and their component minerals, carried out by J. Parry, chief chemist to the De Beers Company. The author is to be congratulated on the production of the most comprehensive and authoritative treatise on the natural history of the diamond that has yet appeared.

C. E. T.

Dr. Frederick Henry Hatch.

Again, after a very short interval, the Editor has to deplore the loss of one of his valued coadjutors and a close personal friend, Dr. Frederick Henry Hatch, who died in London on 22nd September, after a somewhat long illness. Few geologists have been so successful as Dr. Hatch in combining high scientific attainments with great practical knowledge of mining and allied subjects. His work on the development of mineral resources, especially in South Africa, has been of immense value to the Empire, while as a petrologist his name is a household word wherever geology is taught.